Nuclear Waste Services

2022 Inventory for Geological Disposal

Implications Report

July 2025
Reference number: DSSC/407/03

Executive Summary

The UK Radioactive Waste Inventory (RWI) is updated every three years. Based on a stock-take in 2022, the most recent data were published in 2023, reporting on sources, quantities and properties of radioactive waste and materials across the UK.

NWS has updated its inventory for geological disposal (IGD) to take account of the latest UK RWI. This report assesses the implications of the changes to the IGD for the findings of NWS' generic Disposal System Safety Case.

The most notable change to the inventory is the assumption of a 24 GW(e) new build programme[1] (rather than the 16 GW(e) new build programme that was included in the 2019 IGD). The assumed new build inventory has been based on conventional large GW(e) scale reactors, the wastes from which are well understood. There remains significant uncertainty in the quantity of waste from the assumed new build reactors, particularly where it may arise from small or advanced modular reactors (SMR/AMR). The nature of wastes arising from potential AMRs is also uncertain. The implications of the changes introduced in the 2022 IGD are:

- Small changes to the illustrative generic GDF designs (an increase of 10% - 17% in the overall GDF footprint)
- Slight changes to the assumed operational programme (most notably a potential need to increase the throughput rate for MOX and new build spent fuel)
- The conclusions of the 2016 generic DSSC are unaffected
- No new research needs have been introduced

[1] Based on modelling assumptions and policy published under the previous government.

Contents

Introduction 5
The generic Disposal System Safety Case 5
Introduction to the 'Implications Report' 7
Scope of this report 7
Conventions used 8
Waste Groups 8
Data 9
Report structure 10
Changes to the Inventory for Geological Disposal 11
Changes to the inventory scenario 11
Volumes 11
Disposal units 12
Activities 13
Materials data 14
Waste Materials 14
Alternative Scenarios 15
Implications for the Disposal System Specification 16
Knowledge gaps and research needs 16
Summary of the implications for the Disposal System Specification 16
Implications for the generic illustrative designs 17
Disposal Facility Design 17
Number of disposal vaults and tunnels and footprint 17
Operational programme 18
Transport System Design 19
Knowledge gaps and research needs 19
Summary of implications for the generic illustrative designs 19
Implications for the generic Transport Safety Case 20
Transport package safety 20
Transport safety assessment 20
Knowledge gaps and research needs 21
Summary of implications for the generic Transport Safety Case 21
Implications for the generic Operational Safety Case 22
Radiological safety 22
Knowledge gaps and research needs 22

Summary of implications for the generic Operational Safety Case 23
Implications for the generic Environmental Safety Case 24
Operational environmental safety assessment 24
Post-closure safety assessment 25
Groundwater pathway 25
Gas pathway 26
Bulk gases 27
Human intrusion 27
Criticality safety 27
Non-radiological pollutants 28
Knowledge gaps and research needs 28
Summary of implications for the generic Environmental Safety Case 28
Implications for the Disposability Assessment process 29
Conclusions 30
Implications of the 2022 IGD on the findings of the generic DSSC 30
Knowledge gaps and research needs 30
References 31
Glossary 34

Introduction

The generic Disposal System Safety Case

Nuclear Waste Services (NWS) (formerly Radioactive Waste Management Ltd) is the organisation responsible for delivering a programme for the safe, secure and permanent geological disposal of the UK's most hazardous radioactive wastes. Information on the approach of the UK Government and devolved administrations of Wales and Northern Ireland[2] to implementing geological disposal is included in an overview of the generic Disposal System Safety Case (DSSC) [1].

A geological disposal facility (GDF) will be a highly engineered facility, located deep underground, where the waste will be isolated within a system of multiple engineered and natural barriers designed to prevent harmful quantities of radioactivity and non-radioactive contaminants from being released to the surface environment.

To identify potentially suitable sites for a GDF, the Government has developed an approach based on consent: working with interested communities that are willing to participate in the siting process [2]. No site has yet been identified for a GDF although several search areas are being investigated.

To make progress during the siting process, NWS 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 (HSR), for example, granite
- lower strength sedimentary rock (LSSR), for example, clay
- evaporite rock (EVR), for example, halite

The inventory for disposal in the GDF is defined in the UK policy framework for managing radioactive substances and nuclear decomissioning [2]. The inventory includes radioactive wastes and nuclear materials that could, potentially, be classified 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 as they have similar disposal requirements.
- low heat generating wastes (LHGW): that is, intermediate level waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities,

[2] Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy [43] 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. In Scottish policy the term 'higher-activity' radioactive waste refers to ILW and LLW which is not currently suitable for disposal in existing LLW facilities.

together with a small amount of low level waste (LLW) that is unsuitable for near-surface disposal, and stocks of depleted, natural and low enriched uranium (DNLEU)

NWS has developed six illustrative geological 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 concepts.

High-level information on 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 DSSC.

The generic DSSC plays a key role in underpinning the feasibility of a GDF and in undertaking disposability assessments of the various waste packages making up the IGD. This process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Illustrative designs, based on established disposal concepts, are developed to meet these requirements. These illustrative designs 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 illustrative designs.

The generic DSSC demonstrates that geological disposal can be implemented safely and forms a benchmark for NWS to provide waste producers with advice on the packaging of waste for disposal. The suite of documents that make up the generic DSSC, and its high-level structure, are shown in Figure 1.

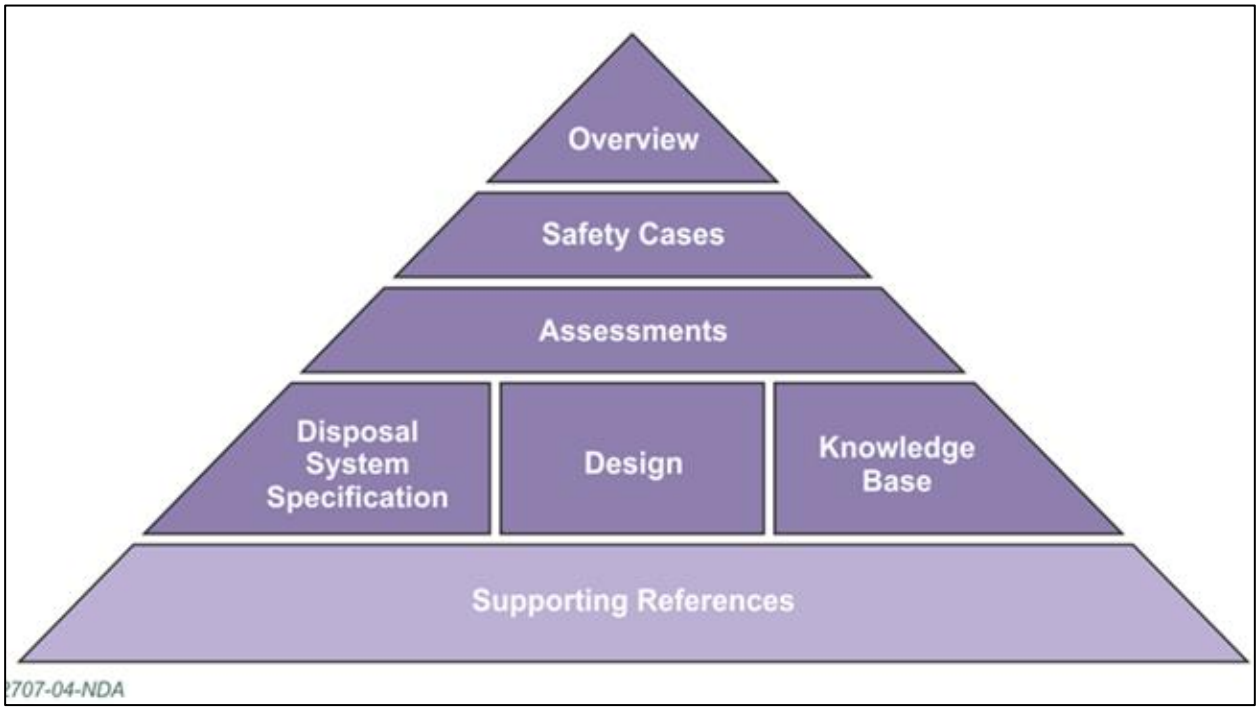


Figure 1 Structure of the generic DSSC.

Introduction to the 'Implications Report'

The current version of the generic DSSC was published in 2016 and was based on the 2013 inventory for geological disposal[3] (IGD) [4]. The IGD is updated periodically, following updates to the UK radioactive waste inventory (RWI)[4] and the most recent iteration of the IGD is the 2022 IGD. This document is the '2022 IGD Implications report' and is one of five reports that deal with the various aspects of the 2022 IGD; the full suite of reports comprises:

- The 'Main report' [5], which describes the key features of the IGD to a technical audience
- The 'Underpinning report' [6] which describes how IGDs are developed and updated
- The 'Implications report' which describes the implications of the changes introduced by the 2022 IGD for the generic DSSC
- The 'Key changes' report [7], which sets out the differences between the 2022 IGD and the previous iteration (the 2019 IGD [8])
- The 'Summary report', which describes the key features of the report to a non-technical audience

The 2022 IGD scenario was agreed in 2022 and the assumptions that have been made broadly reflect the policies, strategies and intentions at that point in time. However, these are all subject to change and the assumptions in the 2022 IGD may not reflect the current position.

Scope of this report

This report aims to assess the changes to the inventory for geological disposal and how they affect the findings of the generic DSSC. The report presents detailed technical information and is targeted at an audience of scientists and engineers, in particular NWS staff and contractors and contains detailed technical information.

The generic DSSC is supported by eight Status Reports that present the scientific and engineering understanding that supports geological disposal in the UK; these reports are summarised in Table 1. Changes to the inventory do not alter this scientific understanding but may result in additional knowledge required to underpin the production of NWS' safety cases.

Any knowledge gaps identified when considering the implications to the generic DSSC as a result of the inventory changes will also be captured and used to inform future NWS research and development work.

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

[4] The UK RWI and IGD differ in two key ways: firstly, the UK RWI reports wastes and materials that are in stock (or expected to arise) from existing facilities, while the IGD also includes wastes and materials from a potential new build programme; secondly, the UK RWI reports all radioactive wastes and materials in the UK, while the IGD reports only those which are expected to be disposed of to a GDF.

Table 1 The Status Reports and the current state of knowledge that they present

Status Report	Current state of knowledge presented
Waste package evolution [9]	The evolution of waste packages (wasteforms and waste containers) during store and after disposal in a GDF
Engineered barrier system (EBS) [10]	The evolution processes affecting the EBS from the construction of a GDF until after its closure
Geosphere [11]	The role of the geosphere in providing isolation and containment of the waste as part of a multi-barrier system
Biosphere [12]	The understanding of the biosphere and NWS's approach to representing it in the generic DSSC
Gas [13]	The understanding of gas generation and migration in the context of GDF safety
Behaviour of radionuclides and non-radiological species in groundwater [14]	The behaviour of radionuclides and non-radiological in a GDF post-closure
Waste package accident performance [15]	The performance of waste packages under accident conditions (fire and impact) during transport and disposal operations
Criticality safety [16]	The supporting studies that demonstrate criticality safety in NWS' safety cases

Conventions used

Waste Groups

NWS' generic disposal facility designs [17] recognise the different packaging and disposal processes for different types of radioactive waste: LLW, ILW and DNLEU are assumed to be disposed of in a LHGW area; HLW, spent fuels (SFs), plutonium and HEU are assumed to be disposed of in a HHGW area. The inventory for geological disposal has been broken down into waste groups (shown in light green boxes in Figure 2) that have been chosen to reflect the different sources of waste and how they will be disposed of in the GDF. The sources of waste considered are:

- legacy: wastes and materials that already exist or that will arise in the future as a result of the operation of existing nuclear facilities
- new build: wastes and spent fuels from the proposed new build programme
- mixed oxide (MOX): arising from reuse of the UK civil plutonium inventory, at this stage only spent fuel is included, irradiation in a pressurised water reactor (PWR) is assumed.

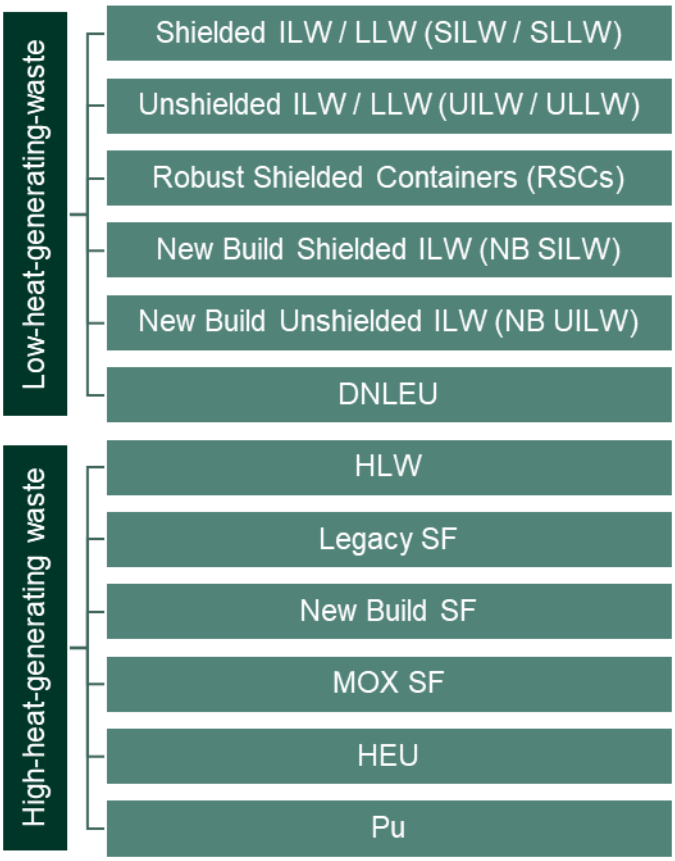


Figure 2 The two high-level partitions of the inventory (dark boxes) and the waste groups (light boxes).

Data

The 2022 IGD includes data for:

- volumes: the stored, conditioned, and packaged volume of the inventory
- activities: information for 112 radionuclides identified as being relevant to geological disposal [18]. Data on selected 'priority' radionuclides[5] are presented along with the total activity from all 112 'relevant radionuclides' and their progeny
- the number of disposal units[6] associated with each type of package
- waste material masses: composition data on two levels: (i) the bulk materials that make up the wastes, and (ii) elemental composition of the wastes
- the properties of the inventory that are relevant to the gas pathway analysis.

All data are presented to three significant figures; this 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. 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 are presented within them. Instead, the totals represent the sum of the data

[5] More detail on priority radionuclides is presented in the Underpinning report.

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

rounded to three significant figures. This approach ensures an appropriate and consistent level of precision in all the data.

Report structure

The remainder of this report is structured as follows:

- *Changes to the Inventory for Geological Disposal* summarises the notable changes in the data between the 2019 and 2022 IGDs
- The assessment of these changes against each aspect of the generic DSSC are discussed in each of the relevant *Implications* sections
- *Conclusions* summarises the implications of the inventory changes on the generic DSSC and associated additional research needs

Changes to the Inventory for Geological Disposal

This section summarises the changes to data between the 2019 and 2022 IGDs. More detailed information about the differences including changes to the underpinning data are reported in [7].

Changes to the inventory scenario

The IGD reference scenario represents NWS' best estimate of how the wastes and materials in the IGD will arise. The size of the assumed new build programme has been increased from 16 GW(e) to 24 GW(e)[7] in the reference scenario. The remainder of the inventory scenario is largely unchanged from the 2019 IGD.

In addition to the reference scenario, NWS considers two alternative scenarios as part of the 2022 IGD. These scenarios represent a considerable change to the scenarios that were used in the 2019 IGD (these were carried over from the 2013 IGD). Whereas the 2019 IGD scenarios considered the sensitivity of the inventory to changes in individual assumptions, the 2022 IGD groups assumptions together into scenarios. Although many of the factors considered in the scenarios are the same as those considered in the 2019 IGD scenarios, the 2022 IGD also considers the impact of advances such as thermally treating the waste and routing the waste to a near-surface disposal facility.

Volumes

The overall change to the volume of waste between the 2019 and 2022 IGDs is small, as shown in Table 2 while Table 3 shows the changes to the packaged volume of each waste group. The key changes to the quantities of waste are:

- A reduction of approximately 96% in the packaged volume of HEU as a result of there being no MOD HEU included in the 2022 IGD
- Changes to the assumed size and composition of the new build programme have resulted in
    - an increase of 53.1% in the packaged volume of new build spent fuel
    - reductions of 11.1% and 2.55% in the packaged volumes of NB SILW and NB UILW. This is attributable to two factors: firstly, the AP1000 is no longer included; based on the packaged volumes of waste presented in the GDA disposability assessment reports, this reactor produced a greater volume of packaged waste per unit of electrical energy than the UK EPR. Basing the estimates solely on the UK EPR has therefore reduced the overall packaged volume of waste. The second factor is that the UK Inventory includes revised estimates for the operational wastes from the UK EPR. The changes to the volume of raw waste are not significant, but changes to the packaging assumptions have resulted in a reduced packaged volume of waste[8].

[7] Based on modelling assumptions and policy published under the previous government.

[8] It is anticipated that SMRs will produce more waste per GW(e) than the large (GW(e) scale) reactors on which the 2022 IGD data are based. There is considerable uncertainty in both the nature and quantity of waste from the assumed 24 GW(e) new build reactors.

Table 2 Changes to the total volume of waste between the 2022 and 2019 IGDs.

Volume	2019 IGD [m^3]	2022 IGD [m^3]	Difference [%]
Stored	342,000	337,000	-1.60
Conditioned	522,000	521,000	-0.191
Packaged	773,000	769,000	-0.498

Table 3 Changes to the packaged waste and material quantities that underpin the 2022 and 2019 IGDs.

Waste group	2019 IGD [m^3]	2022 IGD [m^3]	Difference [%]
Legacy SILW / SLLW	92,600	87,700	-5.30%
Legacy UILW / ULLW	372,000	350,000	-5.79%
RSCs	2,610	2,590	-0.573%
NB SILW	18,900	16,800	-11.1%
NB UILW	22,100	21,500	-2.55%
DNLEU	184,000	192,000	4.33%
HLW	9,880	9,370	-5.18
Legacy SF	17,000	16,600	-2.79
NB SF	39,400	60,400	53.1
MOX SF	11,900	11,700	-1.97
HEU	2,470	103	-95.8
Pu	620	594	-4.16

Disposal units

Table 4 shows the number of disposal units associated with each waste group in the 2019 and 2022 IGDs, along with the percentage change. The total number of disposal units has decreased from 178,000 to 172,000 (3.37%), between the 2019 and 2022 IGDs.

As would be expected from the changes in packaged volume in Table 3, the most significant percentage increase in the number of disposal units is for the NB SF waste group.

Table 4 Changes to the number of disposal units of each waste group.

Waste Group	2019 IGD [-]	2022 IGD [-]	Difference [%]
Legacy SILW/SLLW	5,050	4,780	-5.32
Legacy UILW/ULLW	126,000	119,000	-5.69
RSCs	948	1,070	+12.4
DNLEU	8,380	8,840	+5.45
NB SILW	10,100	7,020	-30.8
NB UILW	8,230	8,960	+8.93
HLW	2,550	2,510	-1.88
Legacy SF	4,160	4,010	-3.46
NB SF	8,940	13,300	+48.4
MOX SF	2,710	2,570	-4.97
HEU	779	35	-95.6
Pu	196	196	0

Activities

The total activity at 2200 has increased by approximately 66% between the 2019 and 2022 IGDs (from 2.82 10^7 TBq to 4.69 10^7 TBq); the evolution of the activity after 2200 (the assumed date of GDF closure) is shown in Figure 3. Table 5 presents the change in activity for each waste group at 2200. The new build waste groups have the largest percentage increases and these are largely driven by two factors: the increase in the assumed size of the new build programme from 16 GW(e) to 24 GW(e); and the spent fuel is assumed to arise later so has experienced less radioactive decay.

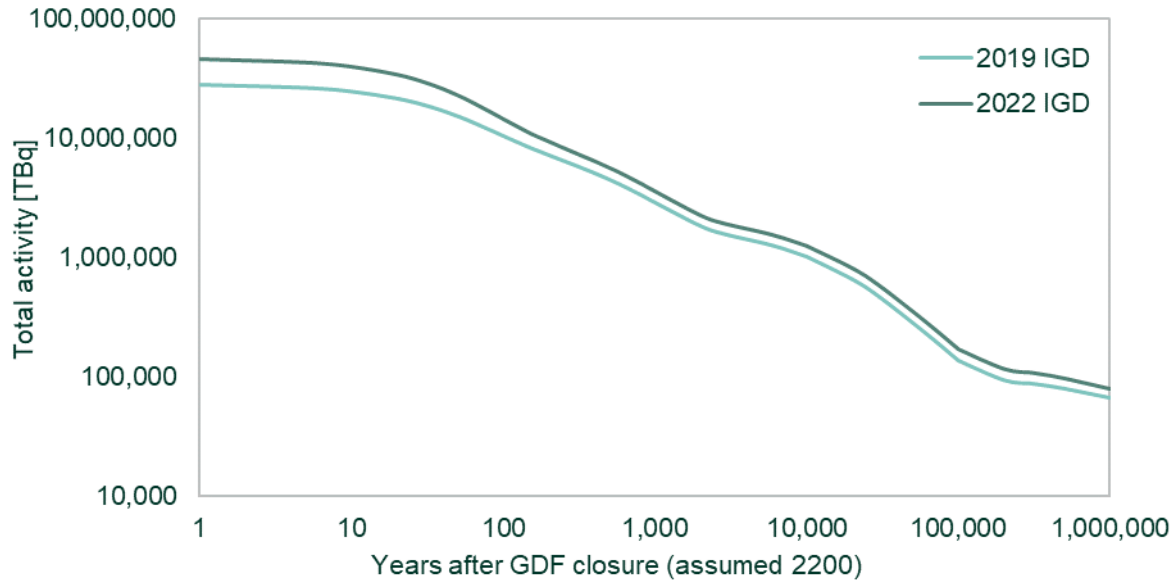


Figure 3 The evolution of the activity in the 2019 and 2022 IGDs.

Table 5 Changes to the activity at 2200 of each waste group.

Waste Group	2019 IGD [TBq]	2022 IGD [TBq]	Difference [%]
Legacy SILW/SLLW	19,400	21,600	+11.2
Legacy UILW/ULLW	398,000	372,000	-6.56
RSCs	3,180	2,680	-15.7
DNLEU	9,800	10,400	+6.48
NB SILW	154	338	+120
NB UILW	793,000	1,910,000	+141
HLW	1,460,000	1,900,000	+30.3
Legacy SF	2,780,000	2,110,000	-24.2
NB SF	19,000,000	37,000,000	+94.7
MOX SF	3,700,000	3,520,000	-4.79
HEU	53.7	2.34	-95.6
Pu	43,700	43,700	0

Materials data

The IGD considers the following types of materials that will be present in the GDF:

- materials associated with wastes; these are discussed below
- materials associated with GDF construction and operating; the estimates of these materials have not changed since the 2019 IGD and no further discussion is presented
- materials associated with conditioning, capping and packaging of the waste; these are not discussed further

Other materials that are inadvertently left behind are referred to as ‘stray materials’ and have not been estimated.

Waste Materials

The changes to the material masses associated with the wastes in the 2019 and 2022 IGD are presented in Table 6. The changes are a result of changes in waste quantities and revised data included in the UK Inventory; these are discussed further in the Key Changes report [7]. The most notable change is the significant reduction in the “unspecified” materials; this reflects the fact that the 2022 IGD is a full update that seeks to assign the unspecified materials, while the 2019 IGD was a light update that did not carry out a full review and enhancement of the data.

Table 6 Changes to the material masses.

Material	2019 IGD [t]	2022 IGD [t]	Difference [%]
Metals	103,000	109,000	+5.92
Organics	10,400	11,200	+8.27
Others	422,000	439,000	+4.03
Unspecified	2,840	2,210	-22.3
Total	539,000	562,000	+4.33

Alternative Scenarios

Alternative scenarios are used to explore the effects of changes in assumptions and uncertainties in data in the IGD. In the 2019 IGD, the sensitivity of the inventory to individual assumptions was explored; however, in the 2022 IGD, the scenarios combine several different assumptions. As such, the way in which scenarios are explored in the 2022 IGD is fundamentally different to the 2019 IGD and they cannot straightforwardly or meaningfully be compared.

Implications for the Disposal System Specification

The Disposal System Specification (DSS) has been developed to describe the requirements on the geological disposal system and is core to NWS' generic 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. There are four parts to the DSS:

- Part A – High Level Requirements [19], which documents the high-level external requirements on the disposal system that derive from the inventory of waste for disposal, legislative and regulatory requirements, and the stakeholder requirements
- Part B – Technical Specification [20], which captures the technical requirements defined by NWS to frame the development of a disposal solution to meet the requirements of Part A
- Part C – Specification for LHGW waste packages [21] (fundamental requirements), which documents the high-level requirements for LHGW waste packages
- Part D – Specification for LHGW waste packages [22] (container specific requirements), which documents the key features for standard designs of waste containers for the packaging of LHGW.

The DSS requires that the IGD includes the waste and material types that would comprise the inventory for disposal in a GDF [2]; these waste and material types have not changed. However, the DSS does need to be updated to reflect the change in the assumed size of the new build programme. Parts C & D, which provide the specifications for the LHGW waste packages are not impacted by the inventory changes.

The DSS requires that the disposal system designs and assessments:

- use the IGD 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 this document.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed to ensure that the DSS remains robust.

Summary of the implications for the Disposal System Specification

The waste and material types that would comprise the inventory for geological disposal are defined in the UK policy framework for managing radioactive substances and nuclear decomissioning and have not changed. The DSS does not impose any requirement that is dependent on the quantities of the wastes and materials. As a result, the DSS is robust to a range of changes in the inventory.

Implications for the generic illustrative designs

The generic Transport System 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 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 Design report [17]. This report also presents the processes of construction, waste package receipt, handling and emplacement, and the design characteristics that the GDF will need to include for the inventory.

Generating the illustrative designs supports development of NWS's understanding of key 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 arisings). The impact of the inventory changes on the generic illustrative designs is reported below.

Disposal Facility Design

The implications of the inventory changes on the generic illustrative designs are described 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 are the same as those which underpinned the GDF generic designs presented in the generic Disposal Facility Design report [17].

Number of disposal vaults and tunnels and footprint

In the generic illustrative designs for all three host rocks, LHGW is disposed of in disposal vaults, while the HHGW is disposed of in disposal tunnels[9]. 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 are presented in Table 7. The key points are:

- The decrease in the number of LHGW disposal units, coupled with changes to the number of each disposal unit type, results in a small decrease (~3%) in the number of disposal vaults in lower strength sedimentary and evaporite rock scenarios and no change in the higher strength rock scenario
- The increase in the number of HHGW disposal units results in an increase in the number of disposal tunnels in all three scenarios (between 16% and 18%)
- The overall increase of the estimated underground areas, or 'footprints', required to accommodate the IGD are between[10] 10% and 17%; this is mainly on the HHGW side of the GDF with a slight decrease in the footprint on the LHGW side of the GDF

[9] It is noted, however, that the disposal concepts differ in each of the host rocks.

[10] These estimated footprints are illustrative and idealised. The layout and configuration of the underground disposal areas depend on a range of factors, including the geology of the site. The layout and configuration will be optimised through the planned design process.

Table 7 The impact of the changes between the 2019 and 2022 IGDs on the footprint and numbers of disposal vaults and tunnels in the different host rock types: Higher Strength Rock (HSR), Lower Strength Sedimentary Rock (LSSR) and Evaporite Rock (EVR)

Rock	Parameter [unit]	IGD 2019	IGD 2022	Difference [%]
HSR	No. LHGW disposal vaults [-]	37	37	0%
	No. HHGW disposal tunnels [-]	321	371	16%
	GDF footprint [km^2]	7.8	9.1	17%
LSSR	No. LHGW disposal vaults [-]	112	109	-3%
	No. HHGW disposal tunnels [-]	353	417	18%
	GDF footprint [km^2]	15.5	17.0	10%
EVR	No. LHGW disposal vaults [-]	94	91	-3%
	No. HHGW disposal tunnels [-]	339	401	18%
	GDF footprint [km^2]	10.5	12.0	14%

Operational programme

The GDF operational programme will be developed and optimised as the GDF programme and waste producers' plans matures. To support NWS and waste producers with planning, underpinned assumptions on waste emplacement dates, sequencing and throughput rates have been made. Overall, the operational programme for the 2022 IGD is similar to that of the 2019 IGD. There are similar durations for disposing of most of the waste types, although the start of waste emplacement is now assumed to be in the 2050's rather than 2040.

For HHGW, there are two campaigns:

- an HLW and legacy spent fuels campaign

  The duration of this campaign has reduced by one year as a result of small reductions in the numbers of HLW and Advanced Gas-cooled Reactor (AGR) spent fuel containers

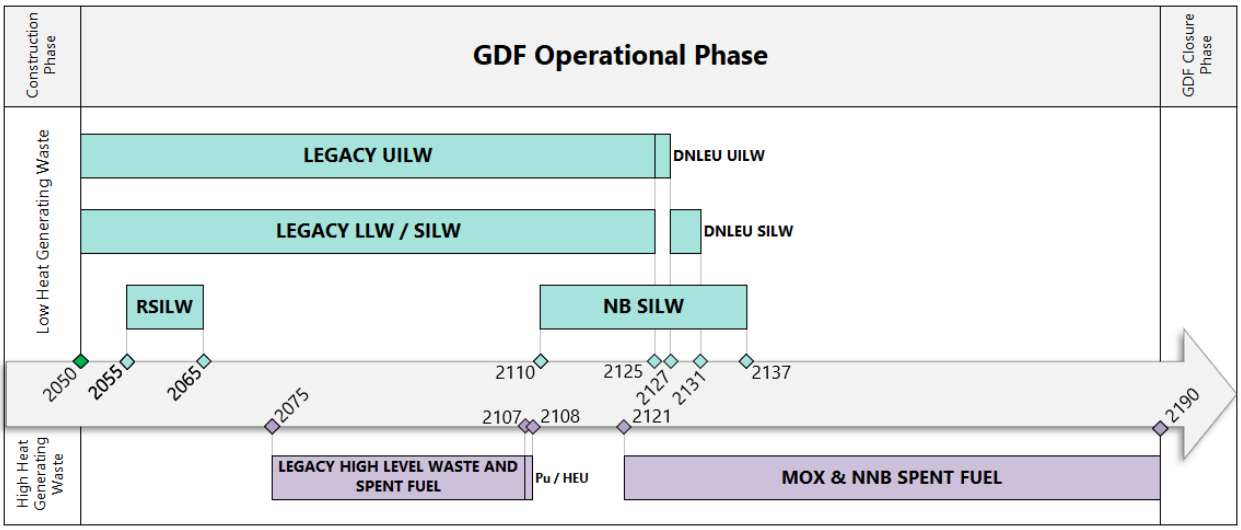
- a MOX and new build spent fuel campaign

  The assumptions of 24 GW(e) of new nuclear power in the 2022 IGD results in additional spent fuel and the assumed throughput of HHGW disposal containers has been increased to maintain the operational end date of 2190[11].

The duration of the emplacement operations for the different waste groups are similar; however, the slight reduction in the number of LHGW disposal units provides a potential opportunity to complete emplacement of LHGW a few years sooner than what was previously assumed based on the 2019 IGD.

[11] The increased throughput rate of HHGW will need additional consideration; this could include logistics and management of heat by considering in more detail the cooling time of the new build spent fuel. This is further complicated by uncertainty regarding the dates of operation for new build reactors.

Figure 4 The operational programme for the 2022 IGD



Transport System Design

The assumptions for the conceptual designs remain consistent with the 2016 generic disposal system designs [23]. There is not likely to be a significant impact on the design of the transport system due to the relatively small decrease in the number of containers to be emplaced in the GDF in the 2022 IGD. However, if the operational end date of 2190 was to be maintained, this would increase the required throughput rate for the HHGW area of the GDF.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed for the generic illustrative designs to remain valid.

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 increase the GDF footprint by between 10% and 17% and require an increased throughput in the HHGW campaign, however these changes do not impact the designs of the transport system or surface facilities.

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 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 is made up of two documents:

- the generic Transport Package Safety (TPS) Report [24], which describes how 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 generic Transport Safety Assessment (TSA) [25], which provides an illustrative evaluation of the radiological doses to operators during routine conditions of transport from the site of arising to notional sites around the UK.

Transport package safety

The 2022 IGD introduces adjustments to the waste containers assigned to waste streams and the overall number of packages of each type; however, it does not introduce any new waste package types. The transport of waste packages to a GDF will utilise large reusable transport containers made from high-integrity materials that provide containment of radioactive materials and shielding from radiation even under transport accident conditions. As no new waste packages are introduced, the range of transport containers currently in development to accommodate them remains unchanged by the 2022 IGD update and hence there is no implication of this inventory update for the generic TPS.

Transport safety assessment

The generic TSA presents an illustrative dose assessment for operators from routine operations with both bounding[12] and best estimate[13] assumptions and compares these results to the targets and limits in the RWM Radiological Protection Criteria Manual (RPCM) [26]. 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 generic TSA assesses seven notional locations distributed throughout England and Wales.

The quantitative safety assessment presented in the generic TSA is also sensitive to changes in the number of transport packages and activities of the waste. The peak transport and disposal

[12] In the bounding case assessment assumes: transport packages all have the maximum allowable surface dose rate; operators have to spend the maximum time carrying out operations near the package; and the maximum throughput package numbers are shipped every year.

[13] The best estimate assessment: applies the calculated package dose rates from the inventory; assumes packages are handled remotely; and applies a transport schedule.

throughputs for LHGW remain the same (~2,500 transport packages per year) and so are unaffected; the peak throughput of HHGW needs to be increased (by approximately 20% during the MOX / new build spent fuel campaign) to maintain the 2190 GDF operational end date[14].

The total annual collective dose to all operator groups associated with the MOX / new build spent fuel campaign is estimated to be around 0.2 – 0.4 person.mSv/yr. The impact of the increased throughput would be a commensurate increase in total annual collective dose. It should be noted that the annual individual dose to each operator group is typically several orders of magnitude below the of 1 mSv/yr and, because more than one operator exists within every operator group, the annual individual dose rate will always be a fraction of this. As such, the changes introduced by the 2022 IGD are not expected to challenge the annual individual operator design target (the 'Basic Safety Objective') of 1.0 mSv/yr.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed to support the TSC.

Summary of implications for the generic Transport Safety Case

The range of transport packages identified for design and development is unchanged by the 2022 IGD and hence there is no implication of this inventory update for the generic TPS. The changes have resulted in a slightly increased expected throughput during with MOX / new build spent fuel campaign which has been assessed and shown not to challenge the Basic Safety Objective for an individual operator annual dose of 1.0 mSv/yr. As such, the conclusions of the generic TSC are unaffected by the changes introduced in the 2022 IGD.

[14] This is based on the assumed operating period for new build reactors which is uncertain and the potential throughput increase of HHGW will require additional consideration as designs mature.

Implications for the generic Operational Safety Case

The generic Operational Safety Case (OSC) demonstrates that a GDF will be safe and the risks will be as low as reasonably practicable (ALARP) throughout its operational lifecycle.

The generic OSC main report [27] is supported by 4 detailed volumes:

- Volume 1: non-radiological and construction safety assessment [28],
- Volume 2: normal operations safety assessment [29],
- Volume 3: accident safety assessment [30],
- Volume 4: criticality safety assessment [31]

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.

Radiological safety

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[15]. 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.

In terms of hazard and risk potential, no changes have been identified that would invalidate arguments supporting the published safety case. The areas of interest are:

- Normal operational dose exposure and the illustrative hazard management arrangements (Isolate)
- Accident scenarios and risk of inadvertent exposure (direct or indirect)

This information is the basis of screening criteria applied in the operational safety assessment [32] that is part of the disposability assessment process.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed to support the OSC.

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[15] 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) [32].

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 2022 IGD do not affect the validity of the extant bounding source terms or the conclusions of the generic OSC.

Implications for the generic Environmental Safety Case

The generic Environmental Safety Case (ESC) [33] 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) [34], which addresses environmental safety during the operational phase of the GDF, and the generic Post-Closure Safety Assessment (PCSA) [35], 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 2022 IGD on the generic OESA and PCSA are described in turn. 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 the following subsections.

Operational environmental safety assessment

The generic OESA presents an assessment of operational discharges associated with all wastes and materials covered by the 2013 IGD. 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 for:

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

These arguments will also apply to the 2022 IGD and it is recognised that, in the future, the OESA will need to address these quantitively.

The generic OESA considers the dose uptake from the release of gaseous radionuclides from LHGW (focussing on H-3, C-14 and Rn-222). The estimated dose uptake is sensitive to: the IGD; the host rock and associated groundwater composition, GDF design and operational philosophy, GDF site's geography, prevailing weather and the ventilation system arrangement; and the host rock's natural background radiation. HHGW is not considered as it assumed to be packaged in durable containers that will retain radionuclides during the operational phase of the GDF.

Table 8 shows the change in the maximum activity of the key gaseous radionuclides[16] in LHGW during the operational period between the 2013 and 2022 IGDs.

[16] In the context of geological disposal, Rn-222 is a short-lived radionuclide (half-life ~3.82 days) and it will only exist where its parent radionuclide (Ra-226) is present. In such cases, it will be in secular equilibrium and its peak activity will be equal to that of Ra-226.

Table 8 The change in the maximum activity of the key radionuclides in GDF gaseous emissions from LHGW between 2050 and 2200 in the 2019 and 2022 IGDs

Radionuclide	Peak Activity (TBq)		Difference [%]
	2019 IGD	2022 IGD	
H-3	33,100	48,000	
C-14	14,600	21,900	
Ra-226	9.51	9.22	

There is clearly a large change in the peak activity of H-3 and C-14, however, this does not affect the conclusions of the 2016 OESA for the following reasons:

- The dose rates reported in the 2016 OESA from gaseous emissions for all organisms were at least an order of magnitude below both the ERICA screening dose rate value of 10 µGy per hour for a terrestrial ecosystem, which reflects predicted no-effect dose rate (PNEDR) values derived as part of the ERICA project, and ICRP derived consideration reference levels (DCRLs) for relevant reference animals and plants. While the dose rates would be higher with the 2022 IGD, they will remain well below the screening values.
- The dose to members of the public presented in the OESA is dominated by Rn-222 and, to a lesser extent, C-14-bearing carbon monoxide, with H-3 providing only a minor contribution. Dose rates to members of the public from gaseous emissions reported in the OESA were below the legal dose limit for members of the public of 1 mSv per year but above the source-related dose constraint of 0.15 mSv per year and the Basic Safety Objective of 0.02 mSv per year. The increase in dose from the changes in the 2022 IGD does not change this.

At this generic stage, the changes to the IGD have no implications for findings of the OESA.

Post-closure safety assessment

Groundwater pathway

The PCSA [35], which supports the GDF generic ESC [33], assesses the long-term impacts of the GDF for hundreds of thousands of years after the facility has closed. The PCSA includes illustrative calculations of post-closure radiological risk[17], associated with disposal of the IGD, as part of this assessment. It is noted that these quantitative assessments used the 2013 IGD as a basis for inventory data, whilst inventory comparisons discussed here refer to comparisons with the 2019 IGD. The implications of previous inventory updates were assessed [36, 37] and found not to significantly alter the calculations and assessments presented in the PCSA.

Changes to the inventory have direct implications for the ESC and PCSA. This is because the amount of protection that needs to be provided by the GDF depends on the hazard presented by the waste inventory. The change in inventory will affect the degree to which barriers will have to fulfil their safety functions in order that the safety of the system as a whole is acceptable.

[17] These calculations are probabilistic in nature, in order to represent uncertainty within the system, and in discussions that follow it is the mean risk that is referred to.

In the previous modelling work for the 2016 DSSC the waste group with the largest associated risk among the LHGW groups are legacy UILW, legacy SILW and DNLEU. The update from the 2019 IGD to the 2022 IGD for each of these groups is presented below.

- Legacy UILW
  This waste group includes the following changes to key radionuclide quantities:
  - increases in I-129 (184%) and Tc-99(11%)
  - small or no change in Cl-36, U-234 and U-238
  - decreases in Se-79 (-15%), U-233 (-9%), U-235 (-3%), U-236 (-13%) and Np-237(-21%).

  Overall this will lead to an increase in the risk associated with this waste group as I-129 is the greatest contributor to risk and its inventory has increased significantly. The change in I-129 is almost entirely due to one waste stream, 2D27/C. This waste stream has been assessed through disposability assessment and it is considered that the I-129 content needs to be reviewed. If the change to the I-129 inventory is discounted, the amount of change to the overall inventory is not significant.
- Legacy SILW
  This waste group includes the following changes to key radionuclides quantities:
  - increases in Ni-59 (19%)
  - small or no change for Cl-36, Cs-135 and U-233
  - a decrease for Zr-93 (-5%), I-129(-27%), U-234 (-3%), U-235 (-16%), U238 (-75%).

  Overall it is expected that the risk will not change significantly as the inventory of the main contributor (Cl-36) has not changed appreciably.
- DNLEU
  This waste group includes the following changes to key radionuclides quantities:
  - increases in U-234 (3%), U-235 (9%), and U-238 (8%)
  - small changes for U-233 (1%)
  - a decrease for U-236 (-3%).

  Overall it is not expected that there will be a significant change in the risk, due to the relatively small changes and because uranium isotopes are typically solubility limited.

In the generic DSSC modelling for HHGW in HSR, it was assumed that only a single container would be breached. In this case it is the inventory per package that will determine the risk. This has not changed significantly and therefore there is not expected to be any significant change in the risk for this scenario.

For models of the generic LSSR concept, the fluxes of radionuclides through the barriers for HHGW would approximately scale with change in inventory. Risks would remain of the same order of magnitude.

Gas pathway

For the gas pathway the key radionuclide is C-14. For the legacy UILW waste group the inventory of C-14 slightly decreases. There are increases for C-14 for the new build UILW and RSC waste groups. The RSC inventory is much small than the other two groups. Further information will be required on the form of the C-14 in the new build UILW to understand its future impact.

This change does not fundamentally change conclusions of the ESC or ways of working, though does potentially increase the level of reliance on barriers that may be required.

Bulk gases

The generation of bulk gases in a GDF may be important, as they can influence the safety functions of the disposal system, for example, via over pressurisation. Also, bulk gases can act as carriers for radiological gases. The bulk gas produced is likely to be dominated by hydrogen, with carbon dioxide and methane also generated. The inventory materials that will have the biggest impact on gas generation rates are likely to be metals and organic materials. In the inventory update these materials see modest or moderate changes in their inventory, as shown in Table 9, with key materials such as Magnox and aluminium showing decreases.

Gas generation rates are dependent on non-inventory factors, such as the site and concept chosen for the GDF as well as wate packaging decisions. This means that there are large uncertainties on gas generation at the current, generic stage. Therefore, the effects of the inventory changes, which are modest for the relevant materials, will be dominated by such uncertainty.

Table 9. Total masses of metals and organics that are important to gas-generation in the 2019 and 2022 IGDs

Material	2019 IGD Mass [t]	2022 IGD mass [t]	Difference [%]
Magnesium / Magnox	6,670	5,890	-11.6%
Aluminium (& alloys)	1,030	852	-16.9%
Stainless steel	36,300	42,300	16.6%
Zircaloy / zirconium	6,330	8,490	34.1%
Cellulose	1,070	1,060	-0.761%
Other ferrous metals	46,100	44,900	-2.74%
Graphite	70,700	65,900	-6.79%
Uranium	1,820	2,040	12.2%

Human intrusion

Human intrusion calculations were not included in the generic PCSA. 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 changes to the inventory are minor and have no impact on such considerations.

Criticality safety

There are no inventory changes that would affect criticality safety for LHGW; however, the inclusion of new spent fuel streams requires consideration for HHGW.

NWS' criticality safety research programme has identified the preferred solutions for demonstrating the criticality safety of spent fuel transport and disposal, setting out the components of scoping level criticality safety assessments for each phase of spent fuel management and disposal [38]. This work has been based on assumptions set out in the 2013 IGD and more recent work [39, 40] has built upon some of the research gaps identified in the options study. Work continues under the criticality safety research programme and will further refine assessments based on available knowledge of the inventory.

For the 2022 IGD, the new build inventories for SMR / AMR have been assumed to be the same, per GW(e), as the inventories associated with the UK EPR. As no new inventory information is presented for these fuels at this stage there are no implications to the generic criticality safety case[18].

Non-radiological pollutants

Scoping studies on hazardous substances were presented in the PCSA for the specific purpose of informing future inventory data requests. The data available for non-radiological hazardous materials has increased with this inventory update but is still limited. The data provided in this update do not affect the conclusions of the PCSA.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed to support the ESC.

Summary of implications for the generic Environmental Safety Case

The changes introduced in the 2022 IGD do not alter the conclusions drawn in the generic OESA and PCSA and therefore do not fundamentally change conclusions of the generic ESC.

[18] The inclusion of SMR fuel types is likely to have minimal implications on the overall generic criticality safety case, as they are expected to have similar characteristics to the PWR spent fuels already included and would largely be bounded by the assumptions made for those types of fuel in terms of fuel material (oxide fuel), initial uranium enrichment and burn-up, i.e. they are not expected to be significantly different from those previously studied. There is greater uncertainty regarding the characteristics of potential AMR fuel types and at this stage it is assumed that they would require individual consideration as they have not been assessed in any detail and could vary significantly from those previously assessed.

Implications for the Assurance of Disposability process

As a part of the Assurance of Disposability process, Disposability Assessment examines the consistency of proposed waste packaging approaches with the current Disposal System Specification (DSS), particularly the detailed 'packaging specifications' embodied in Parts C [21] and D [22] of the DSS[19].

The intent of the Assurance of Disposability process is to ensure that the waste packages produced would be disposable at a GDF. As part of this process, disposability assessment also examines the consistency of packaging proposals with the assumptions made in the generic DSSC and challenges the validity of these assumptions when tested against detailed knowledge of the waste and packaging proposals.

Disposability Assessment 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 the industry.

Changes to the IGD reflect revised understanding of the waste, and revised packaging assumptions, as defined through updates to the UK RWI. Where wastes have been considered through disposability assessment, the assessed position should be reflected in the update to the UK RWI (and subsequently the IGD). The Assurance of Disposability process ensures that continued validity of existing packaging endorsements is maintained through Periodic Review, which provides active management of the status of the endorsements to ensure that they remain consistent with the current safety case and basis for assessment. Noting the close engagement between the Assurance of Disposability team and the waste packagers, the IGD would not be the primary means for communicating any changes to the packaging proposals. As such, the changes to the IGD do not have implications for packaging endorsements that have already been issued.

Where wastes have not (yet) been considered through Disposability Assessment, changes to the IGD would have no impact until such time that the wastes are assessed. At this time, the updated IGD would simply provide the current basis for the check and challenge noted above. Changes to the IGD do not affect future assessments.

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed to ensure that the Assurance of Disposability process remains robust.

[19] *Implications for the Disposal System Specification* identified the need to update the DSS Part A to reflect the larger new build programme. No other implications were identified.

Conclusions

The objective of this report is to assess the implications of the changes to the IGD on the findings of the generic DSSC.

The changes to the IGD between the 2019 and 2022 iterations have been assessed; the most notable changes are:

- the assumption of a 24 GW(e) nuclear new build programme in the 2022 IGD (compared to 16 GW(e) in the 2019 IGD)
- A consequential increase in the quantity of spent fuel and waste from new build[20]
- A 96% reduction in the quantity of HEU resulting from improved assumptions regarding MOD materials

Implications of the 2022 IGD on the findings of the generic DSSC

The changes introduced in the 2022 IGD have been assessed against the generic DSSC and the implications have been found to be small. The implications of these changes are:

- No impact on the Disposal System Specification as the scope of the IGD is unchanged
- Small changes to the illustrative generic GDF designs
    - An increase of between 10% and 17% in the underground footprint of a GDF
    - A decrease of between 3% and 0% in the number of LHGW disposal vaults
    - An increase of between 16% and 18% in the number of HHGW disposal tunnels
    - Changes to the operational programme, most notably an increase of 17% in the throughput of disposal containers during the MOX / NB SF disposal campaign
- No change to the conclusions of the generic Transport Safety Case as no new packages are introduced and the inventory changes will not challenge the Basic Safety Objective dose to operators
- No change to the conclusions of the generic Operational Safety Case which is based on bounding source terms that are unaffected by the inventory changes
- No change to the conclusions of the generic Environmental Safety Case as the inventory changes are sufficiently small to have no affect on the conclusions of the underpinning generic Operational Environmental Safety Case or Post Closure Safety Assessment
- No change to the Assurance of Disposability process.

The inventory changes introduced in the 2022 IGD do not affect the conclusions of the generic DSSC.

Knowledge gaps and research needs

The changes introduced in the 2022 IGD do not result in any new knowledge gaps or research needs that need to be addressed.

[20] Changes to the packaging assumptions mean that the packaged volume of waste from new build actually decreases between the 2019 and 2022 IGDs.

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Glossary

Term	Definition
AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
AMR	Advanced Modular Reactor
Conditioned volume	Volume of the wasteform (waste plus immobilising medium) within the container
Cooling time	Also known as decay period, measured from the end of irradiation
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
DSS	Disposal System Specification
DSSC	Disposal System Safety Case
EBS	Engineered Barrier System
ERICA	The European Rare disease research Coordination and support Action consortium
ESC	Environmental Safety Case
EVR	Evaporite Rock
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GW(e)	Gigawatts electrical
HEU	Highly Enriched Uranium
HHGW	High Heat Generating Waste
HLW	High Level Waste
HSR	Higher Strength Rock
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IGD	Inventory for Geological Disposal
ILW	Intermediate Level Waste
Legacy waste	Radioactive waste which already exists or whose arising is committed in future by the operation of an existing facility
LHGW	Low Heat Generating Waste. Some wastes have negligible heat output; these are included in this category
LLW	Low Level Waste
LSSR	Lower Strength Sedimentary Rock
MOD	Ministry of Defence
MOX	Mixed Oxide Fuel
NB	New build
NWS	Nuclear Waste Services

Term	Definition
OESA	Operational Environmental Safety Case
OSC	Operational Safety Case
Packaged volume	Volume occupied by waste package when waste has been packaged
PCSA	Post-Closure Safety Assessment
PNEDR	Predicted No-Effect Dose Rate
Pu	Plutonium
PWR	Pressurised Water Reactor
RPCM	Radiological Protection Criteria Manual
RS	Robust Shielded
RSC	Robust Shielded Container
RSILW	Robust Shielded ILW
SF	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
SLLW	Shielded LLW
SMR	Small Modular Reactor
TPS	Transport Package Safety
TSA	Transport Safety Assessment
TSC	Transport Safety Case
UILW	Unshielded ILW
UK EPR	UK European Pressurised Reactor™ - The reactor design that is being built at Hinkley Point C
ULLW	Unshielded LLW

Nuclear Waste Services

Nuclear Waste Services
Pelham House,
Pelham Drive,
Calderbridge,
Cumbria CA20 1DB
www.nuclearwasteservices.uk

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