



Nuclear Waste  
Services

IMPLEMENTATION

# 2026 Environmental Safety Case for the LLWR

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# Preface

The Low Level Waste Repository (LLWR) is the United Kingdom's principal facility for the disposal of solid Low Level Waste (LLW). It is a near-surface disposal facility in which waste was disposed in trenches and is now being disposed in vaults excavated into the ground surface. The LLWR is owned by the Nuclear Decommissioning Authority (NDA) and operated on their behalf by a wholly-owned subsidiary division, Nuclear Waste Services Ltd.

We, Nuclear Waste Services, are committed to operating the LLWR as a safe and efficient facility that provides a continuing option for the disposal of LLW in the United Kingdom. This will be achieved consistent with good practice for the near-surface disposal of radioactive waste, in accordance with environmental, health and safety, and security regulation and guidance, and in compliance with the terms of our Nuclear Site Licence and Permit to dispose of radioactive waste. We are also committed to working with the NDA to ensure optimal use is made of the LLWR to support the NDA's mission, in accordance with government policy. This may involve the disposal of a broader range of wastes than just LLW as currently defined in the United Kingdom<sup>1</sup>.

One of the means we use to operate the LLWR safely is to maintain and implement an Environmental Safety Case for the site. This is one of the reports presenting the 2026 Environmental Safety Case for the LLWR – the 2026 ESC. The 2026 ESC is a major update based on a comprehensive review of our previous 2011 ESC and subsequent developments. The 2026 ESC addresses both the environmental safety of the disposal facility and the rest of the site. It considers the disposal of both LLW and some less-hazardous Intermediate Level Waste (ILW). Assessing the disposal of some less-hazardous ILW does not imply any decision has been made to dispose of such waste at the LLWR. The work has been undertaken to understand the safety implications if such a decision were made and hence support consideration of the option by the NDA.

The 2026 ESC is issued under the authority of the Nuclear Waste Services' Executive Director of Sites and Operations.

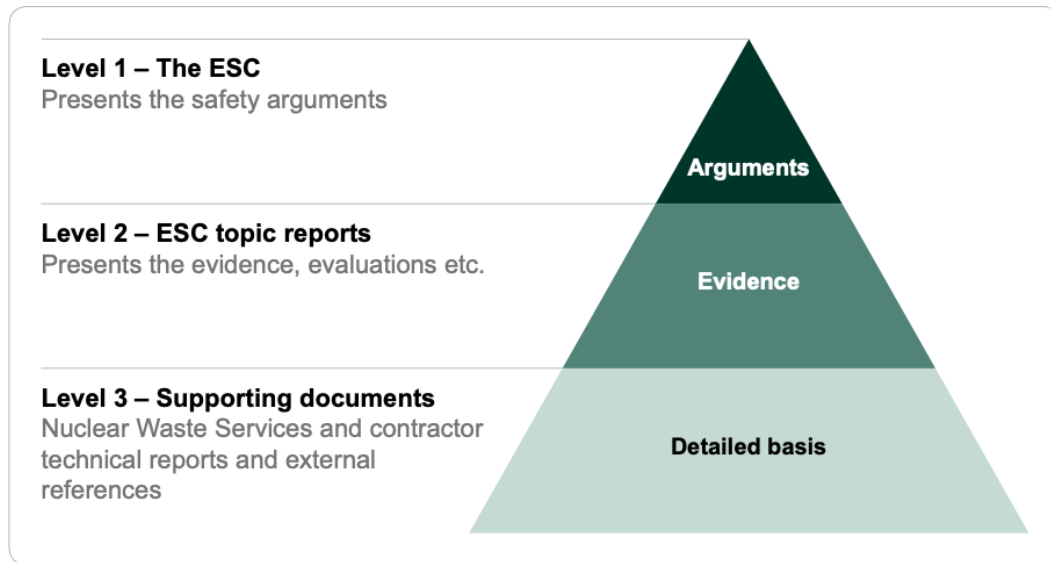
The 2026 ESC consists of documents at two levels:

- A single 'Level 1' report outlines the plan for the development of the LLWR and the main arguments concerning environmental safety and how it is achieved.
- A series of 'Level 2' reports present the evidence that underpins our safety arguments, including descriptions of our management framework, system understanding, design and management choices, assessments and implementation.

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<sup>1</sup> In government policy, LLW is defined as radioactive waste having a radioactive content not exceeding four gigabecquerels per tonne (GBq t<sup>-1</sup>) of alpha or 12 GBq t<sup>-1</sup> of beta/gamma activity.

This is the Level 2 ‘Implementation’ report. The ESC Level 1 and 2 reports are listed in the table below, which also shows for the Level 2 reports the set of arguments for which each report mainly provides evidence. A brief description of the contents of each Level 2 report is also given. The ESC is supported by a large number of technical and scientific reports and references that we refer to as ‘Level 3’ documents. We have also produced a Guide to Key Points of the ESC, to help a wider group of stakeholders understand its nature, conclusions and implications.



<b>Level 1</b>	
Main Report [1]	
<b>Level 2</b>	
<b>Management and dialogue</b>	
Management and Dialogue [2]	Describes our environmental management systems and interactions with regulators and stakeholders
<b>System characterisation and understanding</b>	
Site History and Description [3]	Provides a history and description of the site
Disposal Facility Inventory [4]	Describes the wastes already disposed and wastes that may be disposed at the facility
Engineering Design [5]	Presents the engineering design of the current facility and proposed changes as further disposal vaults are built and the disposal facility is closed

Near Field [6]	Describes our understanding of the chemical and physical evolution of the engineered disposal system
Hydrogeology [7]	Describes our understanding of the geology and hydrogeology of the site
Site Evolution [8]	Describes our understanding of how the site will evolve, with a focus on coastal erosion
Monitoring [9]	Presents our programme of environmental monitoring supporting the ESC
<b>Optimisation and Site Development Plan</b>	
Optimisation and Site Development Plan [10]	Describes our approach to optimising the design and management of the disposal facility and wider site, and sets out our Site Development Plan
Waste Management Plan [11]	Presents our plans for managing the wastes produced by previous uses and operation of the site
<b>Assessments</b>	
Safety Functions [12]	Presents our understanding of how the different aspects of the repository system and its management contribute to the safety of the facility
Engineering Performance Assessment [13]	Presents our analysis of how the various components of the engineered disposal system will perform, which is an input into our impact assessments
Environmental Safety During the Period of Authorisation [14]	Presents evidence that the LLWR is currently being operated safely and will continue to be so during the period that the facility is permitted
Assessment of Long-term Radiological Impacts [15]	Presents evidence that, if the LLWR is managed in accordance with the Site Development Plan, the site will remain safe in the long term
Hydrogeological Risk Assessment [16]	Presents evidence that the disposal facility protects groundwater from both radiological and non-radiological contaminants in the disposed wastes now and will continue to do so in the future

Assessment of Radiological Impacts on Non-human Biota [17]	Presents evidence that the LLWR does not have adverse consequences for non-human biota populations now and will not in the future
<b>Implementation</b>	
Implementation (this report)	Sets out how we use the ESC to manage the site, including setting Waste Acceptance Criteria and other controls on the types and quantities of waste accepted for disposal
<b>Audit</b>	
Addressing Regulatory Requirements and Feedback [18]	Provides a cross-reference between the contents of the ESC and regulatory guidance and feedback

# Executive Summary

This report describes the systems, controls, and organisational arrangements that ensure operations at the LLWR remain within the assumptions, limits, and safety arguments underpinning the ESC.

## Implementation Arrangements and Maintaining the ESC

The Environmental Clearance Certificate (ECC) is the top-level mechanism ensuring that LLWR operations are aligned with the ESC and the Permit. It defines the environmental operating rules, instructions, and assumptions that all site processes must follow, and identifies key environmental equipment subject to enhanced inspection and maintenance.

Supporting the ECC, a structured Requirements Management System (RMS) ensures that engineering design and optimisation work remains consistent with the ESC. Requirements on the closure engineering are traced through the Disposal System Specification (DSS), with linkage into design justification and optimisation studies.

The ESC also defines and informs the LLWR monitoring programme. Monitoring focuses on environmental aspects most relevant to demonstrating ongoing compliance, including groundwater, leachate composition, coastal evolution, and environmental discharges. Results are reviewed routinely and feed back into the ESC.

A formal change management framework, including the Plant Modification Process (PMP), ensures that any proposed modification to plant, process, or design is reviewed for its implications for the ESC. Changes proceed only following assessment and authorisation.

We also maintain the ESC through Annual, Periodic, and Major Reviews. These provide structured assurance that operational experience, monitoring data, and new scientific understanding are incorporated into the ESC and its implementation arrangements. Formal processes exist for evaluating new information outside the review cycles to ensure timely updates where required.

## Waste Acceptance and Capacity Management

The Waste Acceptance Criteria (WAC) specify the physical, biogeochemical, and radiological properties that must be met before waste can be disposed. WAC are derived from several sources, largely directly from the assumptions and outcomes of the ESC, but also from the Nuclear Safety Case (NSC).

The Waste Acceptance Procedure (WAP) governs the full lifecycle of a waste consignment – from enquiry, characterisation, and allocation of capacity through to verification and emplacement. The WAP ensures that only waste consistent with the ESC is accepted and that consignors provide sufficient evidence to support disposability, compliance, and ESC development.

Radiological and non-radiological capacities are derived from ESC assessment models and regulatory criteria. The WAP ensures that disposals do not exceed calculated radiological and non-radiological capacities, and includes escalation routes for strategic decisions on overall capacity use. Emplacement strategies, similarly derived from the ESC, optimise the placement of waste packages to minimise radiological impacts during operations and over the long term.

## **Changes Since 2011**

Since the submission of the 2011 ESC but prior to the 2026 ESC, several improvements have been made to the way that the ESC is implemented. These changes represent an evolution of our approach and draw upon the Environment Agency's review of the 2011 ESC, implementation of the 2011 ESC alongside our operational experience and learning. Key improvements since 2011 include the following.

- Two revisions of the WAC, including revisions to existing WAC and the addition of new criteria. Revisions to the WAC included those on complexing agents and low-activity sources. New WAC that have been added apply to asbestos, non-radiological hazards, activity heterogeneity and discrete items, and active particles. As part of these revisions to the management of hazardous substances and non-hazardous pollutants, materials were grouped into three Categories (1, 2 and 3) according to their required management and disposal limits.
- A new capacity management approach to effectively manage the volumetric, radiological and non-radiological capacities of the vaults, applying an appropriate level of scrutiny during waste acceptance, and arrangements for monitoring capacity usage.
- Implementation of non-radiological contaminant capacities derived from a groundwater pathway assessment.
- Implementation of emplacement strategies to optimise the safety and performance of the LLWR.
- Review of the approach to voidage definition and estimation techniques, leading to new controls on voidage in the WAC.

Other improvements to the site's management processes since 2011 include those listed below.

- The development of the DSS within a RMS.
- Vault closure engineering provisions, consistent with the ESC.
- The introduction of an ECC on site. The ECC states the controls on waste acceptance derived from the ESC. The Certificate also lists equipment with an environmental function used to ensure Permit compliance, which is termed 'Environmental Equipment'.

- Changes to the site change-control process to ensure that the implications for the ESC are assessed when changes to existing equipment ('plant') and management arrangements are made, or where new plant are proposed.

### **Future Changes to reflect the 2026 ESC**

Following the 2026 ESC, several key changes are proposed to further enhance site management and operational safety and to reflect the findings of the 2026 ESC. These include the following.

- Updating the WAC to incorporate new and revised criteria, including those related to discrete items, activity heterogeneity, and low-activity sources.
- Updating vault capacities and emplacement criteria to reflect the latest ESC assessment calculations.
- Enhancing our monitoring of ongoing disposals, including trend monitoring of discrete item activities to ensure they remain consistent with the assumptions in the ESC.
- Continuing the development of the RMS to systematically capture and manage requirements as engineering design and implementation progresses in line with the 2026 ESC.

Such changes would be subject to further consultation with the Environment Agency, including relevant notifications under condition 4.3 of the Permit. We would also consult with consignors, amongst other stakeholders.

### **Potential ILW acceptance**

Government policy now emphasises a risk-informed approach to waste management and optimal use of the LLWR. The 2026 ESC therefore considers the potential future acceptance of less-hazardous Intermediate Level Waste (ILW). While no decisions have been taken, the report outlines additional controls that would be needed for ILW acceptance; these would require further regulatory review and a revised Permit. These include vault-scale activity controls, sub-vault strip management for coastal erosion, updated human intrusion limits, and ILW-appropriate specific activity controls.

These additions provide an evidence base for engagement and planning but do not alter current LLWR disposal practice, which involves the disposal of only LLW.

# Table of Contents

<b>1</b>	<b>Introduction</b>	<b>11</b>
1.1	Objectives	11
1.2	Scope	11
1.3	Structure	13
<b>2</b>	<b>Regulatory and International Context</b>	<b>14</b>
2.1	UK Regulations and Guidance on Requirements for Authorisation	14
2.2	Environment Agency Review of Previous Environmental Safety Cases	17
2.3	UK Government Policy	18
2.4	International Context	18
<b>3</b>	<b>Implementation Arrangements</b>	<b>22</b>
3.1	Environmental Clearance Certificate	23
3.2	Requirements Management System	25
3.3	Plant Modification Process	31
3.4	Change Management and Maintenance of the ESC	33
3.5	Monitoring Programme	35
<b>4</b>	<b>Controls on the Waste Form and the Physical Composition of Wastes</b>	<b>38</b>
4.1	Waste Containers	38
4.2	Grouted Waste Form	40
4.3	Miscellaneous Waste Types	42
4.4	Cap Performance and Waste Voidage	44
<b>5</b>	<b>Controls on the Biogeochemical Properties of Wastes</b>	<b>48</b>
5.1	Complexants	49
5.2	Other Substances	57
<b>6</b>	<b>Controls to Limit Radiological Inventory</b>	<b>60</b>
6.1	Selection of Assessment Cases	63
6.2	Establishment of Radionuclide Screening Criteria	75
6.3	Controls on Total Inventory	78
6.4	Controls on Consignments	93
6.5	Controls Applicable to Sub-Container Scale	120

6.6	Fissile Controls	130
<b>7</b>	<b>Controls to Limit Non-radiological Inventory</b>	<b>132</b>
7.1	Approach to Managing Non-radiological Contaminants	133
7.2	Current Category 1 and Category 2 Contaminants	133
7.3	Controls Derived from Groundwater Assessment	135
7.4	Asbestos	142
7.5	Flammable and Chemotoxic Gases	144
<b>8</b>	<b>Waste Acceptance Arrangements</b>	<b>145</b>
8.1	Waste Acceptance Controls	147
8.2	Waste Acceptance Criteria	155
8.3	Waste Consignment Variations and Disposability Assessment	183
8.4	Emplacement Strategies	184
<b>9</b>	<b>Summary</b>	<b>186</b>
9.1	Key Changes Since the 2011 ESC	186
9.2	Current Operating Model	187
9.3	Changes Required for ILW Acceptance	187
9.4	Future Work Programme	188
<b>10</b>	<b>References</b>	<b>190</b>

# 1 Introduction

## 1.1 Objectives

The Low Level Waste Repository (LLWR) is the UK's principal facility for the disposal of solid low-level radioactive waste. It is a near-surface disposal facility in which waste was disposed in trenches and is now being disposed in near-surface vaults. We, Nuclear Waste Services Limited, operate the facility on behalf of the Nuclear Decommissioning Authority (NDA).

Disposal of radioactive waste and radioactive discharges from the site are regulated by the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2016. Implementation of our Environmental Safety Case (ESC) is key to how we comply with our Permit [19] and follow relevant regulatory guidance [20].

The objective of this report is to describe how we implement the ESC to ensure that the disposal of wastes into our vaults is managed safely and optimally. Changes to implementation necessitated by new developments reported in the 2026 ESC are addressed.

Proposals may be made to seek the necessary permissions to further optimise the use of the facility to dispose of a wider range of radioactive wastes than LLW, based on the safety analyses reported in the 2026 ESC. No decision has been made yet to seek these permissions and the decision would only be made by the NDA after appropriate consultation with stakeholders. The controls that we would propose if a decision were taken to accept for disposal less-hazardous intermediate waste (ILW) and how they would be implemented are described.

The changes to arrangements set out in this report would only be made after appropriate consultation with the Environment Agency, including relevant notifications under condition 4.3 of the Permit.

## 1.2 Scope

The 2026 ESC addresses regulatory requirements for the disposal facility and for the site as a whole. The ESC implementation arrangements described in this report are mainly those applicable to the disposal of radioactive waste in the vaults at the LLWR. Some other aspects, for example, 'change control' of the site facilities, are also covered. Implementing the engineering design assumed in the ESC and managing wastes and contamination resulting from the use of the site for the storage and disposal of radioactive wastes, and previously as a Royal Ordnance Factory, are addressed in other Level 2 reports [5, 11].

The ESC is implemented in the organisation through an Environmental Clearance Certificate (ECC), which ensures that the LLWR is managed in a way that is consistent with the assumptions and outcomes of the ESC.

Waste acceptance is controlled by several means. Waste Acceptance Criteria (WAC) are specified for individual consignments of waste. The WAC address the physical, biogeochemical and radiological properties of wastes and state operational requirements, such as container types. Safe radiological and other capacities are also derived. Both radiological and non-radiological hazards are considered in the derivation of controls. The controls are applied through our Waste Acceptance Process (WAP).

Our arrangements for waste acceptance for disposal are largely derived from the assumptions and outcomes of the ESC. Some of our WAC are derived from the LLWR's Nuclear Safety Case (NSC) and help to ensure operational safety. The outcomes of the NSC Safety Assessments are implemented through Clearance Certificates and 'Requirements for Consignments' (RfC) which are incorporated into our WAC.

In addition to our waste acceptance controls, we use waste emplacement strategies, again derived from the ESC, to reduce appropriately radiological impacts both during operations and in the longer term.

The ESC is a 'live' safety case, which evolves, taking into account new information, both at the time of major reviews and revisions, but also between these iterations. 'Change control' of the ESC itself is addressed in the Management and Dialogue report [2]. Here, the processes are described for ensuring that proposed changes to arrangements and facilities on site are properly assessed for their environmental safety implications, and the ESC is revised appropriately.

We use a Requirements Management System (RMS) to systematically capture the requirements for the engineering design of the disposal facility. The RMS aims to define how requirements cascade down from regulatory requirements, through ESC requirements (among others) and into detailed engineering specification documents.

The 2026 ESC is addressing the ability of the disposal facility to accept less-hazardous ILW as well as LLW. This report describes additional controls that would be required if risk-informed disposal of ILW was introduced at the LLWR.

Hence, this report presents the following aspects of ESC implementation.

- The Environmental Clearance Certificate.
- Requirements management, i.e., the mechanism by which the requirements of the ESC inform the design of the disposal system.
- Change management, including how proposed changes to the disposal system are assessed for their consistency with the ESC and how changes to the ESC may be triggered by new information and operational realities.
- The way in which the ESC informs the environmental monitoring programme.
- Derivation of controls on the properties and quantities of wastes that can be safely disposed at the LLWR.
- The Waste Acceptance Procedure and Waste Acceptance Criteria.

- Emplacement strategies.
- Changes that would be required to accept some, less-hazardous ILW.

Prior to the above, an overview of the implementation of the ESC is provided and the regulatory and international context for the implementation of the ESC is discussed.

The focus of this report is on waste acceptance arrangements and controls. Some other aspects, such as the monitoring programme, are discussed in detail elsewhere in the ESC and this report simply summarises the role played by the ESC and the mechanisms by which the links are maintained, referencing out to further detail where appropriate.

### **1.3 Structure**

This report is structured as follows.

- Section 2 discusses regulations applicable to the LLWR and international context on setting waste acceptance criteria for near-surface disposal.
- Section 3 sets out arrangements for implementing the ESC including our Environmental Clearance Certificate, Requirements Management System, our change management processes and monitoring programme.
- Section 4 discusses the controls on the waste form and the physical composition of wastes.
- Section 5 addresses the physical and chemical properties of the waste that could impact the release of radionuclides.
- Section 6 describes our approach and results for setting limits on the radionuclide content of wastes. This includes controls on total activity, limits for consignments, controls at a sub-container scale and controls for fissile radionuclides.
- Section 7 discusses the controls to limit the non-radiological inventory derived from the assessment of the groundwater pathway.
- Section 8 sets out how the controls are implemented through, and proposed changes to, the WAC and WAP. It also sets out our emplacement strategies.
- Section 9 presents a summary of the key implementation changes since the 2011 ESC, of proposed changes to implement the 2026 ESC under our current operating model, and of high-level changes that would be required if we moved to the acceptance of ILW. It also sets out a high-level future work programme.

## 2 Regulatory and International Context

### 2.1 UK Regulations and Guidance on Requirements for Authorisation

Near-surface radioactive waste disposal facilities in England and Wales require a permit under the Environmental Permitting Regulations (England and Wales) 2016 (as amended) (EPR 16) [21]. The 2009 Guidance for Requirements on Authorisation (GRA) of Near-surface Disposal Facilities on Land for Solid Radioactive Wastes [20] provides regulatory guidance and specifies requirements for near-surface disposal facilities to obtain a permit under EPR 16. The GRA sets out the requirements that the UK environment agencies expect a developer or operator to fulfil when applying for a permit to develop or operate a near-surface disposal facility. It also defines requirements for radiological protection and expectations about ESCs and the WAC which underpin them.

The 2026 ESC also addresses regulatory requirements for the site as a whole, namely the Guidance on Requirements for Release (GRR) [22]. However, the implementation arrangements described in this report primarily relate to the acceptance and disposal of radioactive waste at the LLWR. Therefore, the focus is on the dedicated disposal facility and the requirements of the GRA. No disposal of other 'site wastes' such as in situ structures is being proposed at this time [11].

The principal requirement that is addressed in this ESC implementation document is GRA Requirement R13: Waste Acceptance Criteria. Box 2.1 presents Requirement R13 and the relevant supporting guidance given in the GRA.

#### Box 2.1 GRA Requirement 13 and supporting guidance relevant to this report [20]

##### **Requirement R13: Waste acceptance criteria**

The developer/operator of a disposal facility for solid radioactive waste should establish waste acceptance criteria consistent with the assumptions made in the environmental safety case and with the requirements for transport and handling, and demonstrate that these can be applied during operations at the facility.

##### *Additional GRA text relevant to the setting of WAC:*

§ 6.4.25: Waste characterisation, treatment and packaging are the responsibility of the consignor of the radioactive waste to the disposal facility, but it is the responsibility of the developer/operator of the facility to make sure that the waste accepted for disposal is consistent with the environmental safety case and the requirements at the facility for transport and handling. The developer/operator of the facility needs to establish waste acceptance criteria that can fulfil this second responsibility, and to demonstrate that there are procedures in place to make sure that these criteria are met before waste is emplaced in the facility.

§ 6.4.26: The factors that affect the performance of the waste before and after disposal, and that need to be covered by the acceptance criteria, include the radionuclide content, the chemical and physical form and durability, the susceptibility to microbial action, the thermal and radiation stability, and the mechanical stability.

§ 6.4.27: The waste acceptance criteria should include requirements that ensure as far as reasonably practicable that all waste accepted for disposal is passively safe. The chemical and physical form of the waste should limit detrimental chemical or microbial interactions, and should restrict the release of radionuclides into the disposal environment, in accordance with the assumptions of the environmental safety case. The radiation and heat resistance of the waste form should be in accordance with the assumptions of the case. The waste package should have sufficient mechanical stability to withstand the conditions of transport and handling, and to meet any assumptions regarding structural integrity made in the environmental safety case. The developer/operator will also need to demonstrate that the possibility of a local accumulation of fissile material, such as to produce a neutron chain reaction, is not a significant concern. This demonstration might be achieved by showing that the chance of such an event occurring would be very remote and/or that even if it were to occur the subsequent performance of the disposal system would still be acceptable.

§ 6.4.28: The developer/operator of the facility will need to make sure that the radionuclide content and composition, including the fissile content, of waste consignments received for disposal are sufficiently well characterised to comply with the conditions of the authorisation under RSA 93.

§ 7.2.17: The ESC should support a forward programme for improvements, both to the case itself and more broadly, such as enhancing facility development, operations and management. Operational decisions and practices must align with the safety case.

§ 7.2.18: The ESC should inform facility-specific regulatory limits, underpin waste acceptance criteria and emplacement requirements, and guide environmental and discharge monitoring for compliance.

Other GRA requirements [20] that are particularly pertinent to implementation of the ESC, including setting WAC and defining the WAP, are listed below. How each GRA requirement is addressed, is collated and signposted from within '*Addressing Regulatory Requirements and Feedback*' [18].

- **Requirement R4: Environmental safety culture and management system.** The developer/operator's management system should be such as to ensure that sufficient protection is provided to people and the environment against the radiological and non-radiological hazards of the waste both at the time of disposal and in the future.
- **Requirement R5: Dose constraints during the period of authorisation.** During the Period of Authorisation (PoA) of a disposal facility the effective dose to a

representative member of the critical group should not exceed a source-related dose constraint of 0.3 mSv per year and a site-related dose constraint of 0.5 mSv per year.

- **Requirement R6: Risk guidance level after the period of authorisation.** After the PoA the assessed radiological risk to a person representative of those at greatest risk should be consistent with a risk guidance level of  $10^{-6}$  per year.
- **Requirement R7: Human intrusion after the period of authorisation.** After the PoA the assessed effective dose to any person during and after an assumed intrusion should not exceed a dose guidance level in the range of around 3 mSv per year for prolonged exposures (i.e., those continuing over a period of years) to around 20 mSv per year for short-term (transitory) exposures.
- **Requirement R8: Optimisation.** The WAC, use of the site, and design, construction, operation, closure and post-closure management of the disposal facility should ensure that radiological risks to members of the public, both during the PoA and afterwards, are as low as reasonably achievable (ALARA), taking into account economic and societal factors.
- **Requirement R9: Environmental radioactivity.** It should be demonstrated that the accessible environment is adequately protected from the radiological effects of the disposal facility, both during the PoA and afterwards.
- **Requirement R10: Protection Against Non-Radiological Hazards.** Protection against non-radiological hazards must be consistent with that provided by the national standard at the time of disposal for wastes that present a non-radiological but not a radiological hazard.
- **Requirement R12: Use of site and facility design, construction, operation and closure.** The developer/operator should make sure that the site is used and the facility is designed, constructed, operated and capable of closure so as to avoid unacceptable effects on the performance of the disposal system.
- **Requirement R14: Monitoring.** The developer/operator should carry out a monitoring programme in support of the ESC to monitor for changes caused by construction, operation and closure of the facility.

It is useful to differentiate constraints from guidance levels. The GRA clarifies that doses should not exceed constraints, whilst guidance levels are intended to be indicative of the standard of environmental safety that is being sought, there is not an absolute requirement for such levels to be met. We consider that it is appropriate to use the guidance level as if they are constraints when setting radiological limits for accepting future waste, and this is the approach taken in this report.

Whilst the GRA provides guidance on implementation, it is also important to note that the Permit includes additional requirements of relevance to WAC [23]. These include the following.

- Activity limits on acceptable solid radioactive waste, including any immediate packaging, in which the activity of alpha emitting radionuclides does not exceed 4 GBq t<sup>-1</sup> and the activity of all other radionuclides does not exceed 12 GBq t<sup>-1</sup> when averaged over a consignment.
- Disposal limits for specified radionuclides and groups of radionuclides.
- That waste must be, so far as is reasonably practicable, insoluble in water and not readily flammable.
- A list of materials to be excluded from wastes.

Together with requirements from the GRA, these aspects are considered throughout relevant sections of this document.

In addition, we follow other relevant UK regulations that apply directly to near-surface disposals. These include, for example, Persistent Organic Pollutants (POPs) Regulations, the Control of Mercury (Enforcement) Regulations. Changes to such regulations or in their application will be captured in future WAC and WAP updates, but do not directly form part of ESC implementation, as they arise directly from legislation and regulation rather than the ESC.

## **2.2 Environment Agency Review of Previous Environmental Safety Cases**

We submitted an ESC to the Environment Agency in 2011. The Environment Agency reviewed the 2011 ESC [24] and concluded that LLWR had met all of the requirements specified in the GRA [20]. The Environment Agency identified 29 Forward Issues (FI) which are areas of work where the Environment Agency saw scope for continued improvement in the ESC and its implementation. These largely relate to optimisation or the assessments that are used to define radiological capacities.

We have considered these forward issues in the period between receipt of the 2011 ESC review and submission of the 2026 ESC to the Environment Agency. All of the Forward Issues are addressed in our *'Addressing Regulatory Requirements and Feedback'* report [18].

We have undertaken work and, where relevant, updated assessment cases to address the Forward Issues identified in the Environment Agency's review of the 2011 ESC. Updates to assessments can have direct impacts on the WAC, and are discussed throughout this document. The arrangements set out in this report represent a comprehensive update from what was set out in the 2011 ESC [25]. It integrates operational experience and learning with updated assessments to improve the definition of WAC, the WAP and the wider implementation arrangements.

## 2.3 UK Government Policy

In May 2024 the UK Government and devolved administrations published a new policy framework for managing radioactive substances and nuclear decommissioning [26]. The new policy states that those creating and managing radioactive waste should adopt a 'risk-informed' approach to decision-making throughout the waste management lifecycle, including disposal. The new policy sets the expectation that the best practicable use of resources should be made, including that the NDA make the best use of the LLWR disposal capacity.

In the context of disposal, we interpret risk-informed decision making to require the derivation of safety controls which would include WAC, emplacement strategies and setting maximum capacities for radionuclides and other materials. Meeting these constraints and controls would not necessarily mean that disposal at LLWR represents Best Available Techniques (BAT) but meeting them would be a prerequisite for disposal. The policy advocates other controls such as demonstrating BAT and showing that we are making optimal use of the LLWR and its capacity. Necessary controls would largely derive from the ESC for the facility but also from other considerations such as operational safety.

The 2011 and 2026 ESCs for the LLWR both used risk-based methodologies and hence the current and future WAC, and total radiological capacities derived from the ESCs, are and will be largely risk-based. However, we have assessed the feasibility of accepting less hazardous ILW and considered its implementation by incorporating ILW into our reference inventory. This approach enables us to evaluate the potential and discuss it with stakeholders. Any proposals to dispose less-hazardous ILW at the LLWR site would be the subject of further consultation and preceded by a revised Permit application.

The potential implications are addressed in relevant subsections throughout this document and summarised in Subsection 9.3. In most instances, particularly regarding controls on the physical waste form, we have reviewed the implications and no modifications are necessary. Unless specifically noted otherwise, it should be assumed that no changes to controls are required.

## 2.4 International Context

The International Atomic Energy Agency (IAEA) is the principal organisation for sharing international experiences of safety assessments of near-surface radioactive waste disposal facilities. It has published a range of documents that cover the design, operation and safety assessment of such facilities, the role of WAC and considerations when defining WAC. The IAEA has recognised the importance of setting WAC for many years, with early publications addressing the expected content [27, 28]. In particular, the IAEA Specific Safety Requirements report 'Disposal of Radioactive Waste' includes the following requirement for WAC [29] (§5.1):

*'Waste acceptance requirements and criteria for a given disposal facility have to ensure the safe handling of waste packages and unpackaged waste in conditions of normal operation and anticipated operational occurrences. They also have to ensure the fulfilment of the safety functions for the waste form and waste packaging with regard to safety in the long term. Examples of possible parameters for waste acceptance criteria include the characteristics and performance requirements of the waste packages and the unpackaged waste to be disposed of, such as the radionuclide content or activity limits, the heat output and the properties of the waste form and packaging.'*

In Part 5 of the IAEA General Safety Requirements on 'Predisposal Management of Radioactive Waste', the IAEA notes [30] (§4.24):

*'Waste acceptance criteria have to be developed that specify the radiological, mechanical, physical, chemical and biological characteristics of waste packages and unpackaged waste that are to be processed, stored or disposed of; for example, their radionuclide content or activity limits, their heat output and the properties of the waste form and packaging.'*

And further, that [30] (§4.25):

*'Adherence to the waste acceptance criteria is essential for the safe handling and storage of waste packages and unpackaged waste during normal operation, for safety during possible accident conditions and for the long-term safety of the subsequent disposal of the waste.'*

Considerations relevant to the derivation of WAC are given by the IAEA [29]. These include generic criteria that are relevant for application at the policy level across a range of facilities, for example waste classification definitions that may be specified in national legislation, as well as site-specific and/or facility-specific parameters based on safety assessments for a particular repository. Some of the latter may be based on operational constraints (for example, waste package dimensions), others on engineering requirements (for example, package strength) and others on long-term safety aspects (for example, radionuclide inventory).

The IAEA identifies key aspects to be considered when establishing WAC for low and intermediate-level waste disposal sites [29, 31, 32, 33]. These are summarised in Box 2.2. For many of these, particular emphasis is placed on ensuring no unacceptable impairment of safety and containment characteristics of the waste packages or surrounding barriers. Not all of the aspects identified by the IAEA are necessarily relevant to all categories of wastes (for example, for LLW, the package stability under prolonged radiation exposure and temperature cycling) or all types of disposal facilities (for example, container corrosion in brine).

Nevertheless, they provide a useful source of guidance on aspects that need to be considered in the derivation of WAC.

Whilst some components of the IAEA guidance are of potential importance in terms of environmental safety (for example, radionuclide content, leachability and voidage), some are of greater relevance to operational practices and operational safety (for example, the tensile strength and behaviour of waste packages in a fire). As such they are addressed by operating practices and controls at the site and in the operational safety case for the site. The primary emphasis of this document, however, is the identification requirements for WAC that are necessary to ensure environmental safety.

### **Box 2.2 IAEA WAC requirements [29, 31, 32, 33]**

#### **Summary of IAEA WAC Requirements**

- Limits on radionuclide inventories and/or concentrations in individual waste packages and in the repository as a whole, determined by appropriate safety assessment methods.
- External dose rates and surface contamination of the waste packages for compliance with transport requirements and as necessary for the protection of workers at the repository.
- Packages shall have sufficient strength to bear design loads and be able to withstand accidents. Mechanical properties of the waste form including tensile strength and compressive strength and dimensional stability. Mechanical properties of the waste package including behaviour under mechanical (static and impact) or thermal loads.
- Physical properties of the waste package including number of voids in the container; characteristics of the lidding and sealing arrangements; and sensitivity to changes in temperature.
- Containment capability of the waste package including diffusion and leaching of radionuclides in an aqueous medium; release of gas and tritium under standard atmospheric conditions or the conditions in a repository; capability for the fixation and retention of radionuclides; water-tightness and gas-tightness of the package; and resistance to the action of micro-organisms.
- Chemical and physical properties of the container including materials; porosity, permeability to water and permeability to gases; thermal conductivity; and solubility and corrosion in corrosive atmospheres or liquids such as water or brines.
- Physical, chemical and biological properties of the waste form including; density, porosity, permeability to water and permeability to gases; homogeneity and the compatibility of the waste with the matrix; swelling of materials; thermal stability; generation of gas; percentage of water incorporated and exudation of water under

compressive stress; shrinkage and curing; leachability and corrosion rate; and radiolytic properties.

- Large volume or bulky waste such as contaminated soil or demolition rubble disposed of without packaging must meet national safety requirements.
- Limits on the quantities of free liquids so as not to compromise the isolation of the waste in the repository.
- Limits on materials that could present chemical or biological hazards.
- Combustibility, pyrophoricity and other properties to mitigate the potential impacts of fire.
- Waste package requirements relating to handling, transport and emplacement.
- Package identification unique to each package.

Since 2011, the IAEA has led projects (the PRactical Illustration and use of the Safety case concept in the Management of near-surface disposal (PRISM) and PRactical Illustration and use of the Safety case concept in the Management of near-surface disposal - Application (PRISMA)) to improve near-surface disposal facility management using safety cases, including WAC. We participated in these, building on previous safety assessment initiatives. After PRISMA's completion in 2016, the IAEA launched the Forum on the Safety of Near Surface Disposal, which we were an active member of. The final report includes discussion on limits, controls and conditions specified by the safety case, including that these should extend beyond radiological aspects to specifications on the engineered design and the site's monitoring and reassurance programme [34].

It is relevant to understand how other countries use environmental safety cases to derive WAC. We have, for example, considered examples from France [35], Canada [36], and the USA [37]. Various EU projects – THERAMIN, CHANCE, MICADO, EURAD's ROUTES Work Package and PREDIS – have considered national and facility-specific WAC. The IAEA have recently published guidance on the development of WAC [38].

EU studies note that a lack of international WAC legislation has resulted in varying national approaches, hindering harmonisation [39]. Efforts like the HARPERS project [40] aim to align regulatory frameworks. The sum-of-fractions method for setting radiological limits, as endorsed by IAEA [33], is widely adopted in countries such as France, Spain, and the USA.

Non-radiological WAC, especially engineering criteria, differ across facilities and countries, but there is broad agreement about restricting certain materials. Key WAC aspects include container specifications, voidage requirements, encapsulation procedures, and exclusions for items like explosives and free liquids.

We recognise the diversity of national regulations and facility-specific needs but see value in sharing best practices. We will continue monitoring WAC development globally, focusing on sites comparable to the LLWR.

### 3 Implementation Arrangements

The ESC presents the safety arguments and supporting evidence that it is safe to continue to operate the site and accept further waste disposals. Safety is demonstrated by showing that the requirements set out in the Permit [19] for the site and the relevant regulatory guidance are met.

The LLWR is an operational site. To ensure that the safe operating envelope of the ESC is not exceeded, the site must be operated in accordance with the assumptions and outcomes of the ESC. To ensure that the site is operated in accordance with the ESC, we implement various controls derived from the ESC, as summarised in Figure 3.1.

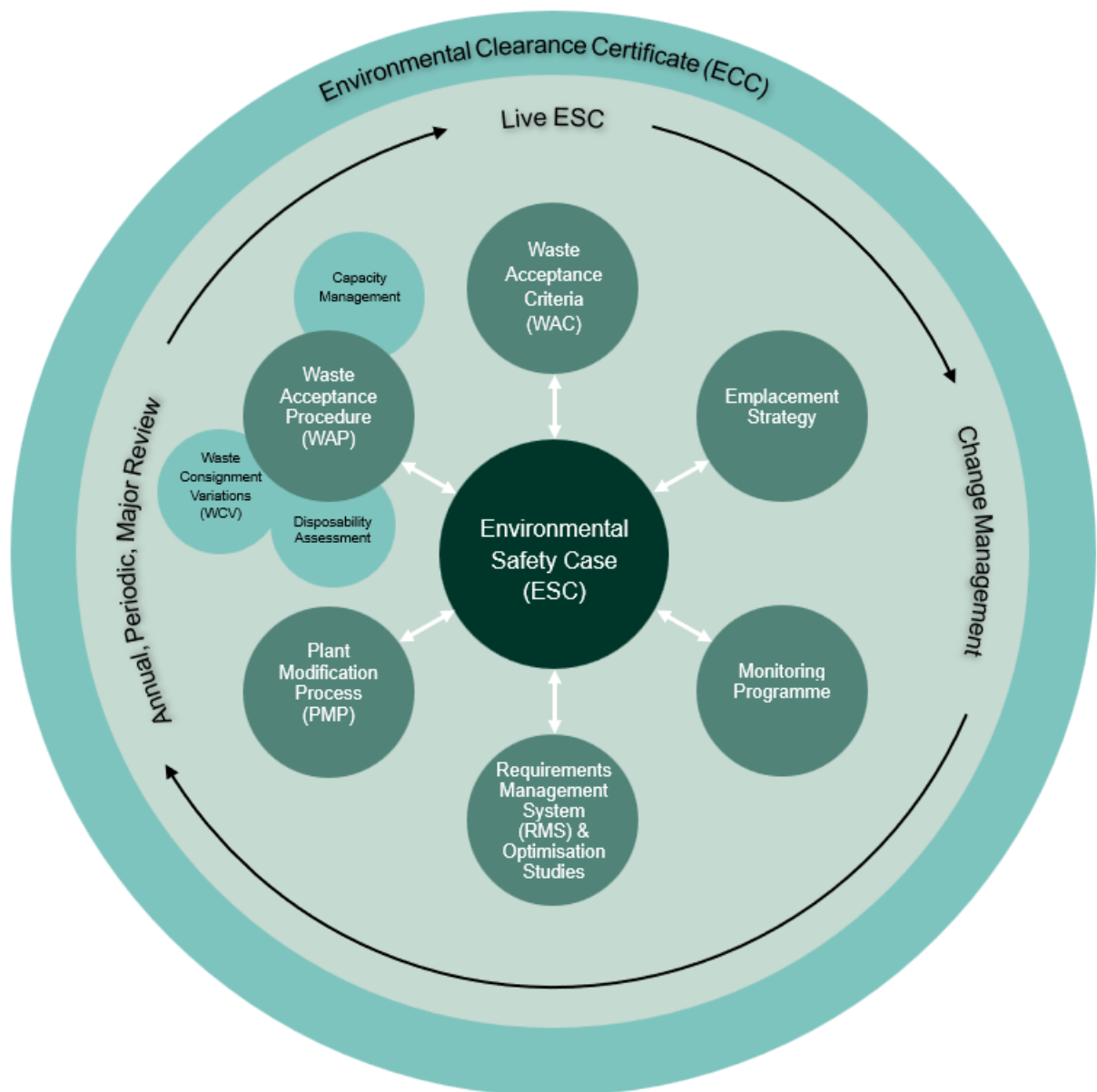


Figure 3.1: Overview of ESC Implementation

The ESC is implemented in the organisation through the ECC. The ECC is the top-level formal mechanism ensuring that the LLWR is managed in a way that is consistent with the Permit and assumptions and results of the ESC. Other means of implementation flow down from the ECC. The ECC is discussed first in this section. Then other specific aspects of implementation of the ESC are covered before waste acceptance is addressed in the following sections. Other aspects covered in this section include:

- the RMS which ensures that design, engineering or optimisation work relating to the LLWR disposal system is delivered in line with the requirements set out in the ESC (such as assumptions, safety functions, and performance criteria);
- the Plant Modification Process;
- change management processes to maintain the 'live' ESC, and subsequent update to implementation arrangements; and
- informing and iterating with the site monitoring programme.

### **3.1 Environmental Clearance Certificate**

The ECC covers all operations at the LLWR site [41]. It is how we document key elements of compliance with the requirements of the Permit. The ECC is the formal mechanism by which we ensure that the LLWR is managed in a way that is consistent with the assumptions and results of the ESC.

The ECC [41] (see Box 3.1) contains one Environmental Operating Rule and three Environmental Operating Instructions that aid in ensuring LLWR is operated within the safe operating envelope defined by the ESC. It also lists five Environmental Operating Assumptions. The ECC also identifies equipment with an environmental function that ensures Permit compliance and compliance with the Water Resources Act or Pollution Prevention Control. This equipment is termed "Environmental Equipment". This equipment is subject to an appropriate Examination, Maintenance, Inspection and Testing (EMIT) regime as detailed within the ECC.

**Box 3.1: Environmental Rules, Operating Instructions and Assumptions of the ECC**

**Environmental Operating Rule**

**(EOR 1)** - All LLW accepted for final disposal will have been checked via its records to confirm compliance with the (radiological) limits and conditions as defined in Schedule 3 of the Permit.

**Environmental Operating Instructions**

**(EOI 1)** - All LLW accepted for final disposal will have been checked via its records to confirm compliance with the WAC or an approved variation to the WAC.

**(EOI 2)** - All LLW accepted for final disposal will only be emplaced after consultation with the ESC Manager to ensure the designated final disposal position in the vault is consistent with the emplacement strategy derived from the ESC. Prior to final disposal the waste must also have been appropriately grouted to fill any accessible voidage.

**(EOI 3)** - All LLW accepted for final disposal will have been checked (via its records) to confirm acceptability against non-radiological and complexing agent capacities.

**Environmental Operating Assumptions**

**(EOA 1)** - An environmental monitoring programme will be implemented.

**(EOA 2)** - Assessment and regular reviews of the ESC will be undertaken.

**(EOA 3)** - A programme of asset inspection and maintenance is in place.

**(EOA 4)** - Changes to design of existing engineered systems related to LLW storage and disposal will be assessed using the PMP process and require consideration of BAT in their development.

**(EOA 5)** - A design and design justification process is in place that takes account of the requirements of the ESC and requires use of BAT.

For each Operating Rule and Instruction, the following are recorded in the ECC.

- Source, i.e. the Permit or ESC.
- Operating Rule or Instruction statement.
- Environmental function.
- Compliance activity.
- Implementing Repository Site Procedures and Operator Instructions.
- Compliance Record Documents.
- Person or team responsible.

The ECC is issued under the authority of the Duty Holder for the LLWR, the Executive Director of Sites and Operations. The relevant Owners are responsible for the implementing procedures and instructions. All staff are required to follow company processes and procedures.

The ECC will be reviewed and revised as necessary against the 2026 ESC and any resulting changes to our Permit, to ensure that the LLWR continues to be operated in accordance with the Permit and the assumptions and outcomes of the ESC. This will include ensuring the ECC sufficiently reflects the requirements of the GRR guidance and the Site-wide Environmental Safety Case.

### **3.2 Requirements Management System**

A Requirements Management System (RMS) is a structured framework that stores defined requirements for a system and shows how they are interlinked and traced through design and construction, including verification and validation that the requirements are met and the system is performing as intended.

The RMS aims to define how requirements cascade down from regulatory requirements, through ESC requirements (among others) and into detailed engineering specification documents. Requirements on the LLWR disposal system are defined to ensure the LLWR Sponsor's requirements are met<sup>2</sup> [42], and to address the key functions, controls and wider performance needs of the engineering design.

The Disposal System Specification (DSS) [43] records all elements of the future LLWR disposal system design. The DSS logically structures the requirements on engineering design derived from decisions made during design and optimisation work [43]. It captures requirements systematically identified through both pre-existing and ongoing optimisation and design studies; hence the requirements themselves can be shown to be optimised. The iterative update of the RMS is key to its use as a tool to capture optimisation outcomes and inform design processes.

The DSS is structured in four hierarchical levels of requirements, with each subordinate level representing an increasing resolution of detail.

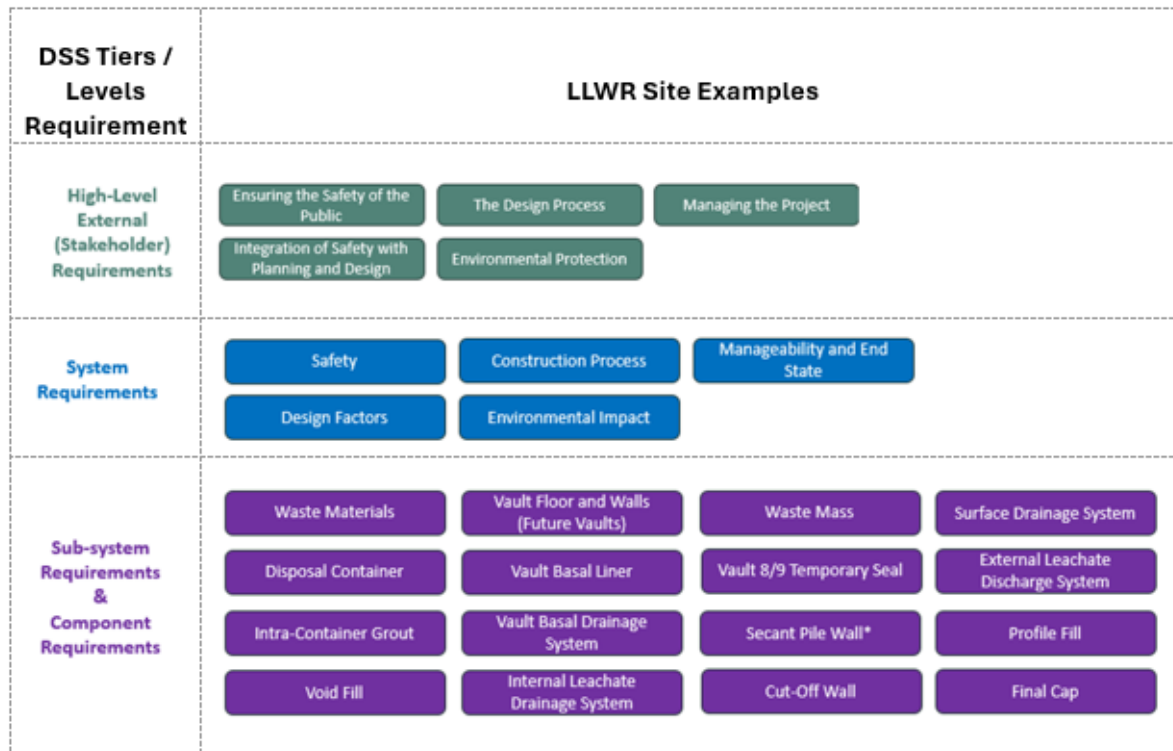
1. 'High-Level External' Requirements
2. 'System' Requirements
3. 'Sub-System' Requirements
4. 'Component' Specifications

This structure is illustrated using a 'Requirements Breakdown Structure' (RBS), as shown in Figure 3.2. Requirements for future vault design, and trench and vault closure engineering are included. Each level contains requirement statements and additional information

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<sup>2</sup> NDA is our sponsor, and has worked with us to devise the "Low Level Waste Repository Sponsor's Needs and Requirements Document" [42] much of which has been derived from regulation and legislation.

(captured within 'attributes') used to aid in the management of requirements. The component-level requirements range from providing clear guidance on specifications, to identifying specific areas where there is flexibility and therefore a requirement for ongoing detailed optimisation through design processes. The DSS covers future design- and construction-related activities until the end of the PoA.



\*the Secant Pile Wall has no component requirements

**Figure 3.2: Requirements Breakdown Structure illustrating the tiered structure of the DSS Requirements with LLWR Site examples**

### Technical policy development

Since 2024, the approach to manage, develop and update requirements has been facilitated by applying a company-wide Systems Engineering ideology, as set out in our Technical Policy [44]. This Technical Policy aligns with ISO 15288, the International Standard for Systems Engineering. An NWS-wide Requirements Management Procedure has therefore been adopted into the Integrated Management System, which sets out best practice for requirements management. The requirements are currently hosted in the IBM Rational DOORS® Next Generation ("DOORS") database tool.

### RMS development

In 2017, a pilot study was performed to explore how an RMS would work and the types of outputs and functionality required for LLWR disposal system needs. The pilot study focussed on the cap, but this was expanded into a full repository-wide requirements framework. The development of the DSS included the use and testing of the requirements contained in initial versions, through optimisation studies for the closure engineering. For the engineering

components whose design has been approved for construction as part of the capping programme, a suite of Design Justification Reports (DJRs) was produced, based on the DSS. The DJRs aimed to demonstrate that the proposed engineered components of the disposal system were designed to satisfy the DSS Requirements, along with any additional engineering specifications and outline installation methods. The DSS Requirements also informed the development of Specification and Construction Quality Assurance documents (e.g., [45] and [46]), which will be reflected in 'validation and verification' plans to demonstrate that the constructed engineering meets the requirements.

To align with our Technical Policy and capture the relevant information from the design justification and optimisation processes, additional 'attributes' were included in DOORS, in addition to the attributes from the original DSS source document. This was to allow the relevant information from the Design Justification Reports to be extracted against each requirement. This provides traceability from the initial requirements statements through to their justification in detailed design, strengthening the connection of safety case development against engineering design and implementation.

This development work is ongoing and planned updates to the RMS are detailed in the Future Work Programme, in Section 9.4.

A worked example is set out in Table 3.1 describing the information included in the RMS for the following Component Specification Requirement:

*The Final Cap and profile material shall provide at least 4 m and preferably 5 m of material between the wastes and the Final Cap surface (Unique reference no. CS-131)<sup>3</sup>*

**Table 3.1: Example attributes added in DOORS to capture requirements justifications in Repository Development Programme Tranche 1**

Attribute	Description	Final Cap and Profile Material Example for Component Specification Requirement CS-131
Contents	The main contents of the requirement statement.	<p>“The Final Cap and profile material shall provide at least 4 m and preferably 5 m of material between the wastes and the Final Cap surface.” (CS-131)</p> <p>This thickness was selected on the basis of parent requirements (SSR-110, SSR-111), corresponding to optimisation</p>

<sup>3</sup> Note this is an example where there is a clear minimum requirement together with a preferred specification, allowing for ongoing optimisation through design within a specific, tightly defined remit. This flexibility in requirements is particularly valuable given the constraints associated with pre-existing facility disposals and engineering.

Attribute	Description	Final Cap and Profile Material Example for Component Specification Requirement CS-131
		<p>arguments in the ESC concerning the thickness required to accommodate differential settlement of the waste and reduce the likelihood of human intrusion (see below).</p> <p>The thickness of the profile fill material is also linked with specifications of the nature of the material elsewhere in the DSS.</p>
Satisfies	Demonstrates the link to parent requirements.	<p>“The Final Cap and Profile Fill material shall be sufficiently thick to reduce the risk of direct radiation dose.” (SSR-110) from Source(s): Cap Settlement report [47].<sup>4</sup></p> <p>“The Final Cap and Profile Fill material shall be sufficiently thick to reduce the likelihood of inadvertent human intrusion into the waste.” (SSR-111) from Source(s): Engineering Design report [5], Cap Settlement report [47].</p>
Design Justification (Tranche 1)	This information is taken (or inferred) from the corresponding Design Justification Report (DJR) and their additional references where applicable, from Tranche 1.	The information here describes the minimum depths achievable for the Profile Fill, over all areas that will be covered by the Final Cap, as detailed in the Tranche 1 Final Cap DJR [48]. These have been identified based on geometrical constraints and are described and justified in the Final Cap Geometry report [49], in turn taking account of the outcomes of the Final Cap BAT [48].

<sup>4</sup> The Cap Resilience report in turn reflects requirements arising from optimisation [48, 153].

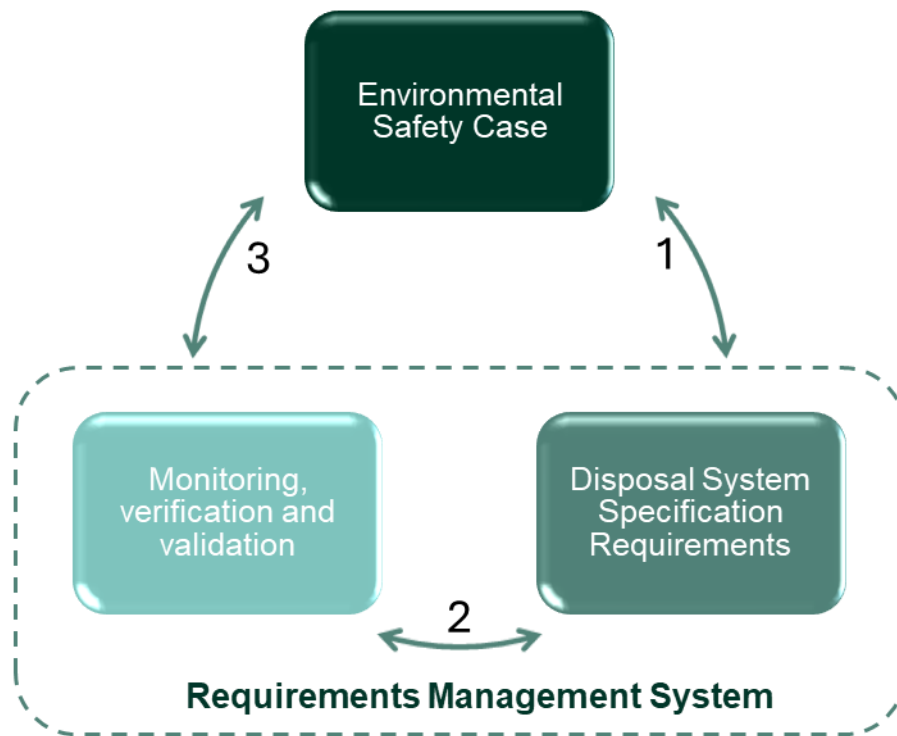
Attribute	Description	Final Cap and Profile Material Example for Component Specification Requirement CS-131
Additional References (DJR)	Additional references that are identified in the Design Justification Report (DJR).	<p>This identifies references, in addition to the source Design Justification report, that provide the backing information for the Design Justification.</p> <p>This includes:</p> <ul style="list-style-type: none"> <li>• Final Cap Geometry report [49].</li> <li>• Final Cap Detailed Design report [50].<sup>5</sup></li> </ul>
Measure-Objective (Tranche 1)	Quantifies the requirement and defines the maximum level of performance that developers should try to achieve. The Objective value is a target that the system provider/developer should seek to attain within the given constraints (e.g. cost, schedule, technical, safety, legal, etc.).	This defines the preferred ("optimised") depth that should be achieved or exceeded to meet the requirement (in this case, defined in the requirement itself, i.e. 5m).
Measure-Threshold (Tranche 1)	Quantifies the requirement and defines the minimum required level of performance. The Threshold value defines the lowest limit of acceptable performance.	<p>This defines the minimum ("lowest") depth that can be achieved to meet the requirement (in this case, defined in the requirement itself, i.e. 4m).</p> <p>The intent is that this will be met for all wastes, but the preferred depth will be met for the large majority of wastes (i.e. wherever site geometry allows).</p>

### Implementing the ESC through the RMS

Figure 3.3 illustrates implementation of the ESC through the RMS. Whilst a formal systems engineering approach would involve setting Sponsor's requirements first, in practice the RMS for the LLWR started from a basis of an existing design, optimisation and wider ESC outcomes. Therefore, the initial DSS was developed through a series of workshops by a multidisciplinary LLWR team [43] and has been subsequently iterated according to the

<sup>5</sup> These references again in turn are based on the underpinning rationale from supporting optimisation documents, as noted in the previous footnote.

process in Figure 3.3. In this figure, requirements from optimisation and design are included in the 'ESC' aspects, as are the outcomes of Engineering Performance Assessment (EPA; see e.g. reference [13]) and modelling programmes.



**Figure 3.3: Implementation of the ESC through DSS requirements, managed within the RMS**

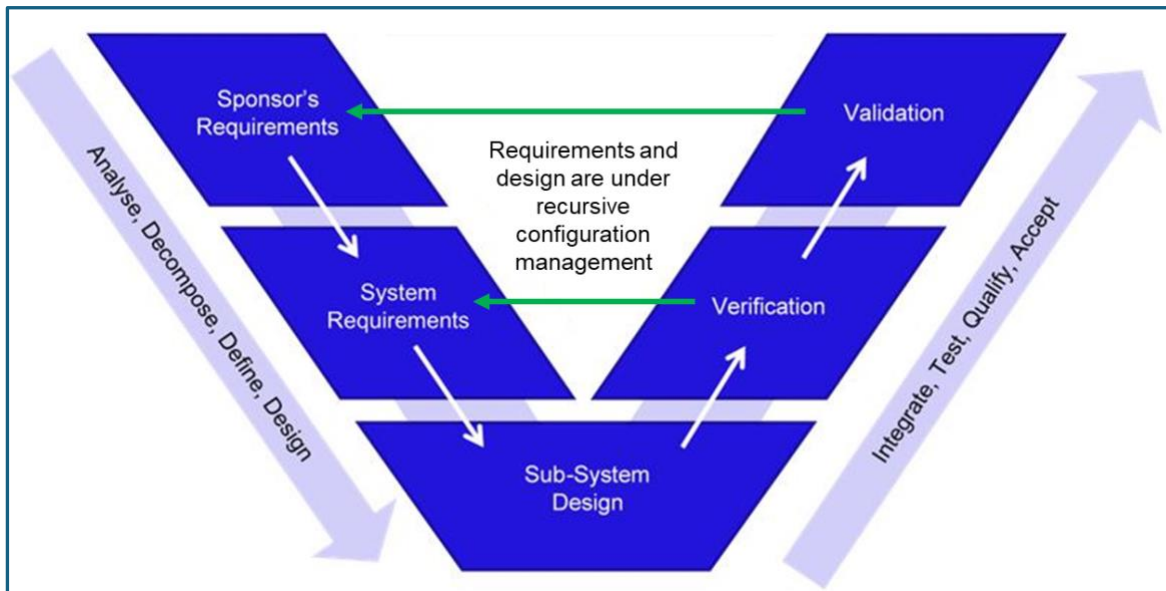
The following expands upon the process illustrated in Figure 3.3, starting in the top box.

- The Environmental Safety Case captures high-level external and system requirements and, through optimisation work, system level requirements. These are also reflected in the associated safety strategy, system understanding, and performance expectations. This includes assumptions, safety functions, and performance criteria for individual engineering components, as part of an overall optimised system. These also take into account ongoing iterations of design and EPA.
- The Disposal System Specification then captures these as formal requirements within the Requirements Management System, ensuring engineering design outputs are justified and traceable (arrow 1). Iteration and feedback is key here, and throughout the process, to ensure conflicting requirements are addressed and updates to the understanding of requirements are fed back.
- This in turn drives the need to verify at the system level, and validate at the Sponsor level, that the requirements have been met (arrow 2). Testing of higher-level requirements (e.g. from IAEA documents, regulatory and good practice resources) can be done through processes such as expert reviews and engagements, and testing through the optimisation process. At the component level, final verification and

validation will be achieved, for example, through monitoring cap performance after construction, or other relevant measurements or demonstrations.

- In the case that requirements need to be revised, traded or removed, this may inform further iteration and optimisation of the design or requirements (arrow 2). Monitoring, verification and validation support the claims and arguments of the optimised ESC (arrow 3). The whole cycle is iterative, based on feedback gained from continuing design and optimisation, wider updates to the ESC as well as other factors, constraints or dependencies that affect engineering design (indicated by the double headed arrows).

The flow-down from Sponsor's requirements to system and sub-system requirements, and their verification and validation is further illustrated in Figure 3.4; forming part of the overall iterative process.



**Figure 3.4: Progressive verification and validation of requirements**

### 3.3 Plant Modification Process

The Plant Modification Process (PMP) [51] is a structured methodology used to manage and control changes to the plant (equipment) and its associated systems, ensuring that any modifications are assessed, authorised, and implemented in a controlled manner. The PMP ensures that all changes are reviewed for their potential impact on facility safety, compliance, and performance.

The PMP provides the practical mechanism through which proposed modifications are evaluated for their compatibility with the assumptions, requirements, and safety arguments presented in the ESC. Any significant change that could affect the nature of disposals, operational controls, or the performance of the disposal system is subject to assessment under the PMP by the ESC Manager. This ensures that environmental safety remains central

to operational decision-making and that any potential divergence from ESC assumptions is identified and addressed promptly.

The PMP is a comprehensive, stepwise methodology designed to ensure that any changes to the plant or its associated systems are properly managed, assessed, and controlled. The process is structured to safeguard facility safety, compliance, and operational performance, including maintaining alignment with the Environmental Safety Case (ESC).

Before a temporary or permanent modification to existing buildings, plant or processes, including changes to a safety case, is made:

- an assessment of its effect on conventional, environmental, radiological and nuclear safety and environmental performance is carried out in addition to specifically considering the impact on the ESC as one of our safety cases;
- the categorisation of the modification, based upon the assessment, must be agreed by appropriate personnel;
- it must be authorised by the appropriate authority (as defined in the Initial Impact Assessment procedure [52]); and
- it must be considered by the LLWR Management of Environmental Health & Safety Committee (MEHSC) [2].

### **PMP stages and ESC considerations**

- **Initiation and Identification:** Any potential modification – whether prompted by operational requirements, technical advancements, regulatory directives, or emerging issues – is first identified and formally documented. At this initial stage, the initiator must consider whether the proposed change could influence the disposal system, its performance, or any aspect that underpins the Environmental Safety Case (ESC).
- **Screening and Categorisation:** The proposed modification is then screened to determine its significance, and this step establishes the tier of assessment required. Changes are categorised based on their potential impact: minor modifications, with negligible or no ESC implications, may proceed through a streamlined review, while those with possible effects on disposals, operational controls, or the long-term performance of the disposal system are escalated for in-depth evaluation. Modifications that could alter, for example, final cap and vault design, waste form, emplacement practice, or inventory characteristics are classified as high significance and are subject to the most rigorous assessment due to their potential implications for the ESC.
- **Impact Assessment:** Depending on the assigned category, a proportionate assessment is undertaken to analyse potential impacts on safety, regulatory compliance, and overall system performance. For changes with greater significance, it is the responsibility of the ESC Manager to ensure a comprehensive review to determine if the modification remains within the bounds of the existing safety case, or

whether it necessitates a revision of ESC assumptions or supporting arguments. Lower-tier changes may require only a summary assessment.

- **Authorisation:** Following completion of the appropriate level of assessment, the modification proposal and its ESC impact analysis are reviewed by the ESC Manager and relevant committees.
- **Implementation and Verification:** The authorised change is then implemented according to a controlled plan, with verification measures in place that reflect the modification's significance. This may involve enhanced monitoring, updated procedures, or additional staff training.
- **Post-implementation Review:** After implementation, the actual impact of the modification is reviewed in accordance with its assessed significance, confirming that outcomes align with predictions and that any unforeseen ESC implications are identified and addressed.

PMPs may only be authored by 'Change Managers', a formal role in our management system. PMPs are appointed following training and assessment. This training and assessment includes familiarisation with the ESC. This ensures that changes are appropriately screened and brought to the attention of the ESC Manager for more detailed assessment where appropriate.

A recent example concerned a proposed modification to leachate management system [53]. A planned upgrade to the leachate collection system was screened through the PMP. The impact assessment focused on whether the change would alter site hydrology or the migration potential of contaminants, both relevant to the ESC. The analysis confirmed compliance, and the modification proceeded.

Another PMP [54] considered the preparation of the area around Vault 8 where the Treated Radwaste Store drums from Winfrith were disposed of. All materials and methods were confirmed to be compatible with site closure and the assumptions in the ESC. The drums were subject to an ESC disposability assessment and approved by the SWMC [55].

Should a PMP trigger a change to the ESC or a more detailed assessment, it would be also be managed via formal change management for the ESC, discussed in the following subsection.

The formal management system arrangements for the PMP process are set out in the *Management and Dialogue Report* [2] (§5.3.1).

### **3.4 Change Management and Maintenance of the ESC**

Waste Acceptance Criteria (WAC) and the WAP control individual consignments but cannot address cumulative trends or systemic changes. For example, the ESC includes assumptions on the volumes of various materials within waste, such as metal or grout, that affect repository performance. Whilst consignment-level variability would not affect repository performance, cumulative changes in trends may be more significant. We undertake Annual,

Periodic and Major reviews to provide assurance that the repository remains consistent with the ESC and within its safety envelope.

Reviews are undertaken at three levels as explained below.

### **Annual Review**

The objectives of the ESC annual review are to:

- collate information on disposals over the last year and review in relation to the assumptions of the ESC, the information including:
  - o radiological capacity usage;
  - o non-radiological capacity usage;
  - o disposal of bulk materials affecting repository performance;
  - o consignments triggering the emplacement strategy, to ensure it remains practicable.
- record significant new monitoring results or other new information and their implications;
- summarise changes to the ESC and associated processes and documentation;
- record significant changes at the LLWR, such that a complete history of the site is maintained; and
- record a review of the ESC Features, Events and Processes (FEP) and Uncertainty Tracker.

*Example:* Recent annual reviews have monitored the trend of decreasing waste receipts, comparing it with the projected forwards inventory in the 2011 ESC. The radiological content of waste has decreased alongside the volume of waste receipts, meaning that we are using a smaller fraction of the site's radiological capacity than was anticipated in 2011 [56].

### **Periodic Review**

We undertake a periodic review of the ESC at intervals of approximately four years. The periodic review focuses on cumulative changes since the last major review. It evaluates whether the ESC remains adequate for the next review cycle, considering construction phases, operational trends, and regulatory developments.

*Example:* The 2024 Periodic Review [57] presented a summary of what we judged to be the most significant changes since the 2011 ESC (aspects related to extended timescales for capping; our decision to surcharge Vault 8; the impact of decreasing waste receipts; our understanding of the expected performance of the final cap; and updated understanding of the near field) and considered their implications for the safety case.

## Major Review

We undertake a major review of the ESC at intervals of approximately ten years, or when triggered by significant changes (e.g. new construction phases or regulatory requirements). It involves a comprehensive reassessment of assumptions, models, and controls, culminating in a revised ESC submission to the regulator. The 2026 ESC is an example of a Major Review.

In addition to these scheduled reviews, there is a formal process for the assessment of new information [58] that may become available outside the regular review cycle. This process ensures that any emerging data, research findings, regulatory guidance, or operational experience are evaluated for their potential impact on the ESC and associated arrangements. If the assessment determines that the new information could affect the safety case, appropriate actions are identified. For example, in 2019, monitoring results revealed elevated concentrations of C-14 in Regional Groundwater downgradient of the site. We assessed the new information (this assessment is principally documented in reference [59]) and decided to continue with a programme of enhanced C-14 monitoring [60]. Our expectation is that releases of C-14 (and tritium) are from the trenches to groundwater and will decrease with addition of the final cap and replacement of the interim cap geomembrane. Other recent Assessment of New Information Forms document the trend of decreasing waste receipts [61] and our improved understanding of local geology and hydrogeology [62] – we assess the implications of this new understanding in full as part of the 2026 ESC. These three Assessment of New Information Forms are documented in the 2022/2023 Annual Review [63].

Where actions are required, they are incorporated into the ESC development plan. This ensures that necessary updates are tracked, prioritised, and addressed in a timely manner. Findings from these reviews or new information assessments may represent or trigger updates to the ESC, which in turn may be reflected in updates to the arrangements set out in this report, such as WAC.

Between Major Reviews, changes to the ESC are documented and recorded in the Annual Reviews of the ESC. During Major Reviews, the cumulative changes are considered and included as appropriate.

The formal management system arrangements for ESC change management are set out in the *Management and Dialogue* Report [2] (§5.3).

## 3.5 Monitoring Programme

The ESC informs the scope, frequency, and methodology of monitoring activities, ensuring that they are targeted at parameters most relevant to demonstrating ongoing compliance with regulatory requirements and safety assumptions. The monitoring programme is delivered by the Environmental Monitoring and Site Characterisation (EM&SC) team, and its links to the ESC, are described fully in the *Monitoring* report [9]. This subsection briefly summarises the way in which the ESC informs the monitoring programme, and vice versa.

The design and implementation of the monitoring programme are driven by the requirements of the ESC. The ESC specifies the environmental parameters and performance indicators that are important for demonstrating ongoing compliance, ensuring that monitoring is focused on those aspects of the site most relevant to environmental safety. The methodology encompasses a risk-informed approach, where conceptual models and risk assessments developed within the ESC guide the selection of monitoring locations, the types of samples collected, and the analytical techniques employed. For example, the ESC identifies areas with elevated potential for environmental impact – such as groundwater pathways, site boundaries, and locations adjacent to engineered barriers – as priorities for enhanced surveillance. The ESC also requires that monitoring results are routinely reviewed and interpreted in the context of the latest safety assessments, allowing for early identification of trends or anomalies that could necessitate changes to operational controls or further investigation [56].

The monitoring programme includes assessment of engineered barrier performance; the performance of which is important to the ESC. Currently, this includes monitoring of the interim trench cap using visual and topographic surveys, leachate levels and temperature data and groundwater quality data. Future monitoring of the final cap will include visual and topographic surveys, settlement monitoring and groundwater quality assessment.

Updates to the ESC are mirrored in the monitoring programme, which evolves to address newly identified risks or to incorporate advances in technology and analytical techniques. For example, if the ESC highlights emerging uncertainties around a particular contaminant or pathway, the monitoring programme will be adapted to ensure these issues are adequately tracked.

Examples of the way in which the ESC understanding informs the monitoring programme include the following.

- Groundwater Monitoring: Boreholes downgradient of the waste disposal area are routinely sampled for radionuclides of most significance to the ESC (e.g. C-14, tritium, Sr-90, see reference [64]), with results compared against ESC-derived performance measures. The ESC concludes that this location is one of the most significant for long-term impacts.
- ESC reviews and subsequent feedback from the Environment Agency emphasised the importance of understanding whether colloid-mediated transport could influence radionuclide migration. Current monitoring has not identified any significant transport of contaminants in association with colloids at the LLWR [65].
- Organic complexing agents can enhance radionuclide solubility and mobility, even at low concentrations. The ESC therefore requires ongoing confirmation that complexants remain within acceptable limits and that any resulting effects are captured within the assessment models. The monitoring programme reflects these requirements through routine leachate monitoring for complexants [66], informing near-field chemical evolution models and assessment model inputs [67]. We control

the quantity of complexing agents that can be disposed of through our WAC and we periodically review the full range of complexants disposed of to the LLWR and present in leachate to ensure that ESC assumptions remain valid [68].

- Coastal change is one of the most influential long-term processes affecting the performance of the LLWR, given its coastal location and the potential for future erosion to impact engineered and natural barriers. The ESC therefore places strong emphasis on understanding and tracking real-world coastal evolution to ensure that safety assumptions remain valid over time. Regular coastal surveys track changes in shoreline position, beach profiles, dune morphology and erosion features. These data provide a direct comparison between modelled projections and actual coastal evolution.
- Boundary Surveillance: Airborne and surface water sampling at site boundaries ensures that off-site migration of contaminants remains within predicted limits. Monitoring at these locations is intensified if the ESC highlights potential pathways or if operational changes occur.

In turn, all monitoring results are reviewed and interpreted within the context of the ESC. This process enables the early identification of trends, anomalies, or deviations from predicted behaviour. For example, if monitoring data indicate a sustained increase in a particular contaminant in discharge data or a deviation from expected groundwater flow patterns, the findings are escalated for further investigation and may trigger a review of operational controls or an update to the ESC. We also undertake an annual retrospective dose assessment [69], primarily using monitoring data, to track overall trends and ensure public doses remain within regulatory limits and the understanding set out in the ESC.

Although the monitoring programme and the ESC are closely connected, the process of iterative feedback is formalised through the following steps.

- Bi-annual liaison meetings between the ESC and EM&SC teams.
- Collaborative development of updated conceptual models, ensuring monitoring understanding is reflected in the ESC.
- Collaborative development of monitoring techniques for specific areas of interest e.g. sampling for colloids and analytical methods for complexants.
- Review of annual monitoring reports by the ESC team, and annual ESC reviews by the monitoring team.
- Periodic and annual ESC reviews include sections that interpret monitoring data for its significance for the ESC.
- New monitoring information relevant to the conclusions and assumptions of the ESC is recorded on an Assessment of New Information form, so that it can be formally reviewed and assessed
- Circulation of reports between the ESC and EM&SC teams.

## 4 Controls on the Waste Form and the Physical Composition of Wastes

This section discusses controls on the physical properties of the waste, waste form and waste container that are relevant to environmental safety, which are implemented through the WAC and WAP. Relevant properties include voidage, surface contamination, additional requirements for specific types of wastes and controls in relation to the performance of the cap.

### 4.1 Waste Containers

#### 4.1.1 Container Specification

Waste containers must meet the requirements for handling and transport as specified by the International Standards Organisation (ISO) for freight containers and meet the UK Transport Regulations [70]. These containers ensure safe handling of the wastes during all phases from the point of waste generation to emplacement in the vault. Containers are deliberately left unsealed at the time of disposal so as to prevent build-up of gases within containers.

Approved containers for use in consigning waste for disposal are listed in the WAC [71] (§L4.1). Half-height ISO (HHISO) containers are the most commonly used container. Wastes that cannot be readily consigned in approved containers may be accepted in other containers, but only with approval prior to use [71] (§L4.2). Non-containerised wastes may also be accepted for disposal at the LLWR and are assessed on a case-by-case basis [71] (§L4.3). Examples of such wastes include redundant fuel flasks and redundant reactor heat exchangers. Each approval considers operational requirements covering waste emplacement, conventional and radiological safety, and potential releases to the environment. The effect of the stacked containers on the vault base slab and associated drainage systems is also considered, as well as impact of different stacking arrangements and heights on volumetric disposal efficiency.

As part of ongoing optimisation, we are currently developing designs for strengthened HHISO containers to better withstand loads from the cap [5]. Once they are available, we expect strengthened containers to be used for future waste consignments in Vault 9 and future vaults. In the 2026 ESC we assume strengthened containers will be used for all LLW consigned to the LLWR after they become available for consignors to use. The WAC will require modification to account for the revised HHISO design, once available.

#### 4.1.2 Durable containers

Waste may be disposed in containers other than the approved disposal container [71] (§L4.2) following approval of a Waste Consignment Variation Form (see subsection 8.3). Some of these "other containers" may be durable in nature.

We define durable containers as those composed of stainless steel, thick-walled concrete or cast iron that are expected to be significantly more resistant to degradation than ISO containers. It is expected some LLW and most ILW in the UK Radioactive Waste Inventory (UKRWI) could be packaged in durable containers. However, our position is to exclude routine disposal of these durable containers. This is because of the potential impact of a substantial number of durable containers on the eroding repository and the resulting consequences for radiological impacts and amenity value of the beach. However, this does not preclude disposal of small quantities of durable containers in the surface vaults, subject to bespoke assessment to determine the BAT approach for that waste.

In order to accept durable containers via variation, our work on coastal evolution [72] showed that they should be spaced apart to allow unimpeded progression of coastal erosion. Stacks of durable containers would need to be adequately spaced apart to prevent any small groups of containers coalescing to form a larger group [72].

Bespoke assessment for durable containers or items would be carried out under our standard Waste Consignment Variation Form process and no change to the WAC is required to accommodate this updated understanding of coastal evolution.

Durable containers would also be considered as Discrete Items (see Subsection 6.5.2).

#### **4.1.3 Controls on the Physical Properties of Waste**

To promote containment and long-term environmental safety, we limit materials that promote corrosion that would accelerate release of radionuclides and other contaminants. Examples of such materials include strong oxidising agents or materials that are corrosive. To address this, the WAC includes a requirement to exclude all strong oxidising agents [71] (§L2.9) and a requirement that waste shall not include corrosive materials that reduce the integrity and performance of a disposal container, unless they are treated, prepared or made safe by an approved method [71] (§L2.10).

Potentially explosive materials could impact radionuclide containment as well as posing an operational hazard. To address this, the WAC defines restrictions on reactive metals and materials [71] (§L2.5), prohibits explosive materials [71] (§L2.6), liquids with a flash point of less than 21°C adsorbed on solid materials [71] (§L2.7) and pressurised gas receptacles and aerosols [71] (§L2.11).

The WAC also includes requirements to exclude free liquids [71] (§L2.7) and soluble solids [71] (§L2.8) that could potentially give rise to release over short periods.

Powders, including incinerator ash, could under certain circumstances give rise to enhanced release and should also be subject to some restriction. We consider that no powder should be disposed of loose within the disposal container in order to prevent short-term release to either leachate or to the atmosphere, including under potential accident conditions. We consider that this is good practice and a component of our approach to optimisation. The WAP requires declaration of quantities of powders in waste streams and individual

consignments. Physical properties of powders are controlled through compression voidage requirements of the WAC. Controls stipulated beyond this are considered disproportionate.

#### **4.1.4 Controls on Surface Contamination**

Non-fixed contamination levels on the exterior surface of disposal containers at the time of consignment must be as low as reasonably practicable and in any case not more than 0.4 Bq cm<sup>-2</sup> for all alpha emitting radionuclides and 4 Bq cm<sup>-2</sup> for all other radionuclides averaged over an area of 300 cm<sup>2</sup> [71] (§L3.5). This derives from the IAEA Regulations for the Safe Transport of Radioactive Material [73] but also provides a good standard of protection to operators at the LLWR. Such levels are consistent with ensuring environmental safety, and experience shows that their application helps minimise releases to leachate.

## **4.2 Grouted Waste Form**

As described in the '*Optimisation and Site Development Plan*' report [10], the grouted waste form was primarily introduced in the late 1980s to minimise voidage, and hence differential settlement of the waste stacks, in order to protect the performance of the cap. Grout also promotes alkaline conditions, which reduces corrosion rates of some metals, alongside providing an effective substrate for contaminant sorption, reducing releases to the environment.

Wastes will continue to be grouted prior to disposal or be grouted in situ. In general, grouting of waste packages takes place at the LLWR. However, there is the potential for pre-grouted waste packages to be sent to LLWR from consignor sites; these packages would be assessed on a case-by-case basis. We would require information on the grout used by the consignor, and would expect a similar performance and evolution to the LLWR grout.

### **4.2.1 Near-field Modelling**

An understanding of the evolution of grouted wastes and the influence of the grout on conditions in the vaults has been developed for the ESC, based upon application of sound scientific understanding of the relevant processes supported by the outcomes of detailed biogeochemical modelling and experimental studies [6]. This has shown that the grout provides functions that are relevant to safety including those set out below.

- It is anticipated that reducing conditions will be maintained in the vaults for the whole period before coastal erosion disrupts the repository. Within the containers, the grout porewater will remain above pH 12 for thousands of years. Such conditions will provide good retention of many contaminants within the vaults, for example, the solubility of uranium under these conditions is limited by uranium(IV) dioxide (amorphous UO<sub>2</sub>) to very low concentrations, and technetium will be stabilised in the less soluble Tc(IV) oxidation state.
- The grout will also provide a good sorbing substrate for dissolved species, particularly metal contaminants.

- Experimental studies of C-14-bearing waste materials, such as graphite, have found that a large proportion of the C-14 from some materials is released as inorganic carbon species, mainly carbon dioxide. Under the high pH conditions in grout porewater, inorganic C-14 species will dissolve and react to precipitate carbonate minerals such as calcite ( $\text{CaCO}_3$ ). These will be stable in the repository conditions and immobilise the inorganic C-14. A significant proportion of the C-14 inventory may be immobilised in this way, although this depends on the materials it is associated with as, for example, C-14 released by corrosion of activated metals is predominantly in the form of organic species.

Our near-field modelling studies examining the release of contaminants from the waste have explored the implications of different modelling assumptions for the amount of contact between grouted waste and infiltrating water, different proportions of grout in containers, and the influence of cellulose degradation products on the grout pH [6], and their implications for contaminant release.

The near field conditions will provide good retention of many contaminants within the vaults, for example, uranium solubility under these conditions is limited to very low concentrations, and technetium will be also stabilised in its less soluble oxidation state.

The modelling also shows that whilst the grout provides important safety functions in addition to void filling, the pH within a container is not very sensitive to the proportion of grout in wastes [6]. On this basis, WAC on the quantities of grout are not considered necessary. However, where significant changes in waste treatment practices occur or we propose to accept different waste types, we will use our established processes (e.g. disposability assessment, Waste Consignment Variation (WCV) and monitoring of ongoing disposals) to ensure that no significant changes in waste form are introduced without further assessment of the implications for environmental safety.

#### **4.2.2 Grout Formulation Development**

The 2011 ESC described how we encapsulate LLW using an alkaline hydraulic grout, comprising a mixture of 3:1 Pulverised Fly Ash (PFA) to Ordinary Portland Cement (OPC), water and a superplasticiser, Sikament 700 [25].

When the 2015 UK Government announced its intention to phase out coal-fired electricity generation by 2025, it was recognised that this posed a risk as the production of PFA is a by-product of coal combustion. To mitigate this risk, work commenced in 2017 to seek alternative sources of PFA or other suitable materials to replace PFA, and to achieve this the Grout Development Project (GDP) was initiated.

In addition to the PFA shortage, the cement industry is shifting from pure OPC (CEM I) to Portland Limestone Cement (PLC /CEM II) (which contains 6–20% limestone), introducing uncertainty in OPC supply.

A Grout Functional Specification [74] was subsequently developed which considered the overarching ESC requirements for grout formulations.

Four alternative formulations have thus far been developed and tested, following down-selection of materials in coarse formulation [75], fine formulation [76] and fine formulation trials with CEM II [77].

Further optimisation trials were undertaken on the superplasticiser used in grout, which changed from Sikament 700 to ViscoCrete 150-PF [78]. The local water supply also changed, although neither of these later changes proved significant to grout performance.

Blending trials have been undertaken to optimise the preferred formulation [79] and are progressing to partial scale-up (500 m<sup>3</sup>) to take the new grout formulation to Technology Readiness Level 7 (TRL7), which generally is regarded as scaled-up technology before inactive trials can be undertaken at full scale (TRL8), in preparation for full implementation on plant with radioactive waste (TRL9).

Recognising the need for commercial resilience of powder supply and certainty that any grout formulation we develop should meet the requirements of the Functional Specification [74] for encapsulation of wastes disposed of at the LLWR, changes in the cement powders and additives markets will be monitored on an ongoing basis.

Prior to taking any new formulation to TRL9, the LLWR would undertake a technical review of the implications across the ESC. We would also consult with the Environment Agency prior to implementing any change in the grout formulation.

The development of grout formulations is a continuous process for the future that seeks to optimise the LLWR grout in light of new developments in the cement industry, and the outcome of any performance monitoring of waste packages consigned to the repository. It will also address any implications for modelling of the repository near field in the ESC.

### **4.3 Miscellaneous Waste Types**

Some waste types that might be contained within the grouted waste form may have properties that could lead to enhanced releases of radionuclides or non-radiological contaminants compared to other waste types. Examples of such wastes include those containing absorbed liquids, soluble salts, ion exchange materials and powders. Controls on these aspects are discussed below.

#### **4.3.1 Free Liquids**

Free liquids are excluded from wastes by existing controls. Nevertheless, it is desirable to retain the ability to accept wastes with minor quantities of absorbed liquid provided that the liquid is not released subsequent to disposal. The WAC [71] (§L2.7) require that absorbed liquids must be fixed in a Suitable Solid Matrix which will not result in release of liquid under applied loads of up to 400 kN m<sup>-2</sup>. This was derived as part of the waste form development work in the early 1990s [80]. The criterion is consistent with the following.

- A stack height of four standard half-height containers each at the 42 t maximum weight limit.

- A final cap height of 15 m as considered at that time.

Since this WAC was specified, the concept of higher stacking of wastes within the vaults was introduced as part of the 2011 ESC of up to nine standard half-height containers [81]. However, in the 2026 ESC, we have assumed, in our optimisation and engineering studies, that the stacking height will be up to seven HHISOs high [5, 10]. Revised designs for the final cap have also been developed [5]. We have reviewed the basis for ensuring retention of absorbed liquids if present in disposed wastes.

Based on the maximum standard container weight limit of 42 t and the cap design assumed in the 2026 ESC [5], that maximum applied loads at the base of any stack will not exceed  $340 \text{ kN m}^{-2}$  in any vault. To enable absorbed liquids to be retained, we will retain the current WAC based on an applied load of  $400 \text{ kN m}^{-2}$ . For standard weight containers, this requirement will be achieved with no further constraints on waste emplacement. If consignments of greater weight are accepted, then specific assessment will be carried out either to limit the loads at the base of the stack to acceptable levels or to require that absorbed liquids are not present. Such assessments may be necessary, for example, for containers with particularly heavy wastes or for disposal of non-containerised wastes.

#### **4.3.2 Soluble Salts and Ion Exchange Materials**

Existing controls require soluble salts and ion exchange materials to be conditioned in a Suitable Solid Matrix and that we approve the method prior to disposal [71] (§L2.8 and §L2.14 respectively). This requirement is specified to minimise the potential for enhanced aqueous releases of radionuclides or non-radiological contaminants. Such effects could potentially give rise to short-term peaks in discharge to the marine pipeline or to groundwater at later times. We therefore intend to retain the present WAC requirements for such waste types. Treatment also ensures that any moisture associated with such materials is suitably treated prior to disposal. The requirement to condition soluble solids is also potentially important in terms of minimisation of voidage (Subsection 4.4).

We request that consignors provide a description of their approach to grouting trials for both soluble salts and ion exchange resins, so that we can assess any potential incongruence with our grout or other aspects of our disposal concept. We also may request leach testing for mobile species using a standard 'tank test' and set an appropriate leaching limit based on the leaching species of concern for the waste in question, typically for oils we use a total organic carbon (TOC) value of 15 ppm after 28 days.

#### **4.3.3 Powders**

Powders, including the finer grain sizes of incinerator ash, could under certain circumstances give rise to enhanced release. Conditioning of powders is also beneficial to cap performance (Subsection 4.4) and to reduce rates of contaminant transport in groundwater (Subsection 5.2.2). For this purpose, incinerator ash is regarded as a powder.

## 4.4 Cap Performance and Waste Voidage

Prior to closure of the LLWR, an engineered cap will be progressively installed over the trenches and vaults. The purpose of the cap is to:

- limit infiltration into the wastes ensuring low releases of contaminated leachate from the facility and limiting the rate of waste degradation and the subsequent expression of voidage relating to biodegradation;
- reduce the radiological impacts of certain radioactive gasses;
- ensure that erosive effects are limited as far as practicable;
- prevent or discourage intrusion into the wastes; and
- isolate the wastes from the environment, including reducing doses from external irradiation.

Future cap performance is influenced by differential settlement. This can occur where there is differing voidage and degradation properties between wastes, or between wastes and vault components. Confidence in cap performance therefore requires controls on voidage and the degradation properties of wastes so that they are compatible with ESC assumptions and meet requirements for the cap's long-term performance. Voidage reduction is also one of the main design functions for the grout used in vault disposal containers.

### 4.4.1 Voidage Between Containers and Within Container Structures

Significant void spaces between container stacks post-emplacement will be filled with gravel prior to vault capping. Even so, some minor spaces between containers are anticipated to remain.

In addition, there is also some voidage associated with the structure of the disposal containers, principally due to the corrugations and corner structures necessary for container strength. Whilst accessible voidage inside the container is filled by grout, that external to the container or otherwise not accessible for grouting will remain as voidage at waste emplacement. It is estimated that in total this voidage, after cap emplacement, represents about 5.5% of the vault volume [47]. This voidage is relatively uniformly located across the vaults. It is estimated about half of this will be eventually eliminated as the containers degrade with time due to the effect of corrosion and resulting expansion of the metal of the containers [47].

### 4.4.2 Total Potential Voidage

Total Potential Voidage (TPV) is the voidage that remains in the container after grouting of waste consignments or that is subsequently formed by waste degradation and settlement. In our WAC [71], it is defined as the sum of inaccessible voidage, compression voidage and biodegradation voidage. Components of TPV are defined follows.

- Biodegradation Voidage associated with materials that can degrade over time. It is equal to the total volume of paper, cardboard, cotton, putrescible materials<sup>6</sup> and other readily degradable materials. It excludes, for this purpose, wood and man-made polymers such as plastics and resins.
- Inaccessible Voidage is voidage within a container, including within the waste, which will not be readily penetrated by grout during the conditioning process prior to disposal at the LLWR.
- Compression Voidage is the volume reduction that would occur in any materials present in the waste, other than those materials considered under Biodegradation Voidage, under applied loads. In our WAC, we define Compression Voidage in terms of the response of materials to loads of up to 400 kN m<sup>-2</sup>. Examples of materials with significant compression voidage include unconditioned powders such as incinerator ash, and soft wastes not subject to supercompaction.
- Ullage Voidage is the voidage present at the top of containers as a result of underfilling with grout.

In the 2011 ESC [25] a limit of 20% TPV (excluding Ullage Voidage) was introduced to the WAC to control voidage in wastes [71]. This was based on calculations of cap resilience in response to TPV for the 2011 ESC. Our understanding of cap performance, including assessments of resilience to settlements, have developed since then. The following subsections review the 20% TPV limit in the context of these updates.

#### **4.4.3 Cap Resilience Assessments**

In addition to tighter controls on TPV, confidence in cap resilience has further increased through design optimisation and an enhanced understanding of cap material performance since the 2011 ESC. In particular the following optimisation and improvement in understanding has contributed to improved confidence in the cap resilience [13].

- Cap resilience has been improved by the inclusion an additional metre of profile fill, and the inclusion of granular backfill material for the profile fill (which maximises strain distribution).
- Reduced infiltration calculations in comparison with the 2011 ESC, based on literature evidence that, with good construction quality, the composite system of Bentonite Enhanced Sand (BES) and geomembrane will perform well for periods approaching 2,000 years.
- The use of surcharging (i.e. preloading of the waste stacks) for containers accepted prior to limits on TPV in Vault 8 and part of Vault 9 to express compression voidage prior to capping of the vaults and trenches. In cap resilience assessments, surcharging has been assumed to express at least 8% of the TPV, reducing the assumed average voidage of disposed containers to 11%. Waste to be disposed in

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<sup>6</sup> Subsection 5.1.8 provides more details on putrescible materials.

stronger HHISOs will not be surcharged, but will be accepted under WAC to limit TPV.

- A literature review has identified that the strain tolerance of the low permeability layer materials is better than assumed in the 2011 ESC.

In the most recent cap resilience assessment for Vault 8, a range of scenarios were considered relating to settlement and its impact on cap performance [82]. It is recognised that the greatest risk for differential settlements is where the waste stacks are adjacent to hard points or edges (for example stacks next to the vault walls), or where neighbouring stacks are at differing heights to each other (e.g. a six-high stack neighbouring a four-high stack). These scenarios are referred to as a 'sensitive locations' in the assessment.

In each of the sensitive locations, two voidage scenarios were considered; stacks with an average TPV of 19% which is close to the average voidage determined from reviews of disposed of containers, and stacks with 35% average TPV<sup>7</sup>, which is close to the 99<sup>th</sup> percentile of disposed waste voidage. For each voidage scenario four- and six-high stacks were considered to explore a full range of conditions, including representation of surcharge. Results from these assessments, for all credible scenarios including stacks with 35% TPV, confirm that for the optimised cap and profile fill design the strain induced in the cap is within a tolerable envelope.

The site continues to receive wastes in containers that will need to be surcharged prior to vault capping in order to express container deformations to ensure a stable formation for cap construction,, so that they will be expected to have similar settlement properties to Vault 8 wastes, that is within the tolerable envelope of strains for the cap.

Future containers are currently planned to have a strengthened design so that a stable formation for the cap can be provided without the need for surcharge. Surcharge is not required for confidence in cap resilience over these wastes. TPV controls will ensure that voidage remains well within the envelope required for cap performance.

#### **4.4.4 Limit on Total Potential Voidage**

The current limit for TPV in the WAC is 20%, which excludes Ullage Voidage [71] (§L2.16). This is a container-specific limit, for simplicity. The limit will ensure acceptable voidage in every stack, consistent with ensuring confidence in cap resilience. Given this focus on overall stack voidage, there is scope for flexibility in individual container voidage, so long as it can be demonstrated that overall voidage are controlled. In addition, the majority of containers currently received have a TPV significantly less than the 20% limit. In the time period 2016 to 2024, received wastes had an average TPV of 10% [83].

As such, containers with greater than 20% TPV may be accepted by variation, and managed under our emplacement strategy (See Subsection 8.4).

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<sup>7</sup> The 19% and 35% values came from regression analysis in 2013 of the 2011 ESC inventory data. However, these values are assumed to remain appropriate for the current assessments.

On this basis it is not planned to change the current TPV limit of 20%. We will, however, keep this limit and the flexibility to accept other containers by variation under review, to ensure that voidage management and emplacement procedures remain optimised and proportionate.

## 5 Controls on the Biogeochemical Properties of Wastes

This section identifies potential waste components, or their degradation products, that could adversely influence release of radionuclides or non-radiological contaminants and therefore increase impacts. These waste components may be materials that are disposed in bulk (e.g. cellulose) or substances that are present in smaller amounts associated with a disposed material (e.g. decontamination agents). We are principally concerned with components of the waste that:

- have the potential to form complexes with other contaminants and enhance their mobility;
- may impact the biogeochemical evolution of the near field, locally or otherwise, in a way that enhances contaminant release.

We are also interested in materials or substances that have the potential to have chemotoxic impacts in the environment. In this regard, we implement controls to limit the inventory of non-radiological contaminants. These controls and the materials that they affect are discussed in Section 7.

The biogeochemical properties of the near field and the materials that exert a significant influence on its evolution are described in our '*Near Field*' report [6].

In 2011 [25], we identified materials and substances that have the potential to interact with the wastefrom in a way that could enhance contaminant release by reviewing the full list of material types in the then current UKRWI [84]. We used our understanding of the near-field conceptual model and the factors relevant to contaminant release to identify the materials that warranted further study. We also reviewed the results of the environmental monitoring programme to identify any other potentially significant species.

We arrived at the following list of materials:

- complexants in decontamination agents;
- cellulosic materials;
- putrescible materials;
- non-cellulosic polymers;
- ion exchange materials;
- superplasticisers;
- other materials such as oils, powders, graphite, sulphates and nitrates.

Our work in 2011 highlighted complexation as the principal mode by which waste components, or their degradation products, could interact with the wastefrom to adversely

influence release of radionuclides or non-radiological contaminants. The majority of the materials and substances listed above are included on the basis of their ability to form complexes. Since 2011, most of our work in this area has focused on such complexants.

In 2013, we undertook an extensive programme of work to better understand the range of complexants in the repository and their potential impacts [85]. On the basis of this work and further quantitative assessment, we proposed appropriate WAC for control of complexants, which were adopted following our Permit being granted in 2015 [86]. Complexants are discussed in more detail in Subsection 5.1.

For the 2026 ESC, we have not identified any new substances or species that have the potential to enhance contaminant release.<sup>8</sup> In our development of the ESC, we have, however, revised our view on topics that affect our consideration of the existing list of materials. For example, we have revised our understanding of the near-field conceptual model (see our '*Near Field*' report [6]).

In the subsections that follow, we review our detailed consideration of the materials that can interact with the wastefrom in a way that could result in enhanced contaminant release to form an up-to-date view on any necessary controls on the acceptance of such materials.

## 5.1 Complexants

Many of the substances considered in this section are included on the basis that they themselves or their degradation products are complexants.

A complexant (or complexing agent) is a ligand, which may be an individual atom, molecule or a functional group, that can bind to a metal ion with one or more bonds. There are many chemical species in the repository that have the potential to act as complexants. The complexants of interest to the ESC are those that may increase the mobility of radionuclides or other contaminants present in the LLWR near field, thereby increasing their potential to cause environmental harm. The potential for any complexant to impact repository performance depends on:

- its ability to increase the mobility of radionuclides by increasing solubility of the contaminant or decreasing the ability of the radionuclide to sorb onto solid surfaces;
- the rate at which the complexant or complex degrades in the repository environment.

Complexants were a major topic of our work in the years after the 2011 ESC. In October 2013, we applied to the Environment Agency to vary our Permit to dispose of LLW, which prohibited disposal of complexants at the time [87]. The request to vary the Permit was supported by several assessments carried out since the 2011 ESC [88], including a review of the potential effects of complexants on contaminant transport at the LLWR [85]. This review identified the types of complexants that we expect to be present in LLW and outlined the

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<sup>8</sup> We have identified new materials that are relevant to our control of the inventory of non-radiological contaminants, discussed in Section 7.

position that was adopted in the WAC [71] (§L2.13). It concluded that some substances, which may be complexing by virtue of their chemical mode of action, should be specifically excluded from control as complexants. These complexants are associated with:

- ion exchange materials;
- superplasticisers (as a component of cured cement, concrete or grout);
- coagulants and flocculants;
- low molecular weight ions that are commonly occurring or ubiquitous in the natural environment (e.g. ammonium ions).

Complexants may be generated in the repository near field by degradation of other waste materials. Our review [85] concluded that the types of waste materials that may result in complexant generation are:

- non-cellulosic polymers;
- cellulosic polymers;
- putrescible materials.

For the reasons discussed in the following subsections, we concluded that these materials do not require control on the basis of their capacity to degrade to form complexants.

We concluded that the complexants found in decontamination agents, including inorganic and organo-phosphates, carboxylic and polycarboxylic acids, and aminopolycarboxylic acids, have the greatest potential to adversely affect contaminant mobility in the repository near field. Aminopolycarboxylic acids, such as ethylene-diamine tetra-acetic acid (EDTA), having the greatest potential to affect repository performance due to their chemical stability in the near field and high affinity for a range of metal ions.

A quantitative assessment of the impact of EDTA on repository performance and capacities [89], and further calculations to estimate radiological and non-radiological capacities [90] underpin the current WAC, including a site-wide capacity of 1,000 kg of aminopolycarboxylic acids.

The materials discussed in this introduction are addressed in the following subsections. We do not propose to alter the current WAC for control of complexants, i.e. we do not propose to implement controls on materials that have the potential to form complexes other than those complexants that are often found in decontamination agents, and we consider that the current WAC for control of these materials remain to be appropriate. The current WAC are discussed in Subsection 8.2.

### **5.1.1 Complexants in Decontamination Agents**

Complexants are often found as active ingredients in the decontamination agents used in the decommissioning process. Decontamination agents are used to remove radionuclides from surfaces by employing complexants to increase the solubility and decrease the sorption affinity of otherwise immobilised contaminant species. As a result, quantities of the

complexants associated with decontamination agents can be found in certain decommissioning waste streams. In the repository, these complexants have the potential to enhance radionuclide and non-radiological contaminant mobility in a way that may cause adverse environmental impacts, even at low concentrations.

### **Current WAC**

Requirements for control of complexants in wastes are outlined in our current WAC [71] (§L2.13), which categorises complexants in two ways:

**Category 1:** materials that require control but do not require an allocation of repository site capacity; the quantities of the materials must be recorded in the relevant section of the Waste Consignment Information (WCI) form. These complexants are:

- carboxylic acids: examples include citrate, picolinate, oxalate and formate;
- inorganic compounds: for example, tri-polyphosphates.

**Category 2:** materials that require an allocation of repository site capacity. These may be accepted for disposal subject to there being sufficient capacity in the repository. This is assessed based on information in Waste Characterisation (WCH) forms submitted by the waste consignor and in the UKRWI. Waste consignors are consulted in cases where the use of the capacity would be grossly disproportionate to the volume of waste. It is the responsibility of the consignor to ensure that the total disposal of controlled materials for each waste stream does not exceed the capacity allocated to that waste stream.

A key distinction between Category 1 and 2 complexants is often that Category 1 complexants are expected to degrade rapidly under repository conditions, whereas Category 2 complexants are expected to persist in the repository near field for an extended period, because they are believed to be chemically resistant and do not biodegrade under repository conditions, or it cannot be demonstrated confidently that they will not persist.

At present, the only Category 2 complexants are the aminopolycarboxylic acids (APCAs): ethylene-diamine tetra-acetic acid (EDTA), diethylene-triamine penta-acetic acid (DTPA) and nitrilo tri-acetic acid (NTA).

Category 1 complexants in waste consignments are recorded by weight on the WCI and entered into eMWaste, our waste tracking system.

Category 1 complexants are only permitted in quantities less than Bulk Chemical Compound quantities<sup>9</sup> in waste. Our reviews have demonstrated that the impacts of complexants other than aminopolycarboxylic acid complexants do not impact significantly on the overall performance of the LLWR. However, we decided to limit the disposal of bulk quantities of complexants of any type, because of the potential break down of this conclusion at very high complexant concentrations.

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<sup>9</sup> For these purposes, a Bulk Chemical Compound quantity is defined as material present in mass quantities no greater than 1 kg per ISO container and is made up of specific purposeful accumulations in one space of (typically) manufactured salts of elemental combinations, usually having anionic and cationic components [71].

Category 2 complexants require more stringent control and consignors must be allocated a capacity for such complexants on a waste stream basis at the characterisation stage. Category 2 complexants in consignments are recorded by weight in the WCI and entered into eMWaste, which subtracts the weight of the complexants in the consignment from the overall site capacity of 1,000 kg. The site capacity for APCAs is underpinned by numerous assessment calculations that show that the risk associated with certain loadings in porewater is within acceptable limits [68, 89, 90, 91, 92, 93].

In addition to these controls, the WAC [71] requires that:

'Customers shall ensure that Best Available Techniques have been adopted in the management of wastes to minimise the quantity of Chemical Complexing and Chelating Agents, described in Category 1 and Category 2 above, requiring disposal at the LLWR.'

Other proprietary chemicals and reagents containing complexants not listed may be accepted for disposal but only with prior approval of a WCV form with 'Suitable Supporting Justification' (see reference [71]). Such materials may need to be fixed, prior to consignment, in a Suitable Solid Matrix (see reference [71]) that will not readily release that component, as demonstrated using an agreed leach test if appropriate.

### **Further developments**

In the context of ESC assessments, EDTA is taken to be representative of the broader class of aminopolycarboxylic acid complexants, and, therefore, the entire class of Category 2 complexants, because it is the most abundant of this class of compounds. Our efforts have focused on increasing confidence in the reference concentrations of EDTA used for trench and vault assessments and maintaining regular monitoring of complexant disposals to ensure alignment with ESC assumptions [68]. We have also demonstrated that:

- annual complexant receipts remain very low [56], and cumulative amounts are not expected to exceed the overall site capacity;
- relaxation of Permit conditions to allow complexant disposal has not resulted in a significant increase in quantities received, likely supported by ongoing efforts to discourage complexant use at consignor sites.

We also updated our review of the complexants that may be present in the near field to determine whether any additional controls were required. We did not identify any additional species that require control as complexants [68].

### **Implications of revised Near-field conceptual model**

As noted above, a key distinction between Category 1 and 2 complexants is often that Category 1 complexants are expected to degrade rapidly under repository conditions. This is often based on arguments related to their susceptibility to biodegradation. For example, citric acid is a Category 1 complexant that is commonly found in decontamination agents. It is known to be readily biodegradable (the citric acid cycle is used by organisms that generate

energy via respiration, either anaerobically or aerobically). Therefore, it is possible that the mechanism for removal of some Category 1 complexants from the near field is compromised by the high pH environment that we now expect to be prevalent in the vaults.

Under the assumption that citric acid could persist in an abiotic near-field environment, we undertook a programme of chemical speciation modelling to assess the significance of citrate complexation under high pH near-field conditions and evaluate whether the assessment model requires consideration of the effect of citrate on contaminant solubility and sorption [94].

This work concluded that citrate complexation of metal contaminants under pH 12.5 conditions is weak and is not expected to affect solubility or sorption processes, thus, there is no requirement to represent the effects of citric acid in ESC assessment calculations [94]. Furthermore, citrate and other organic complexants that are highly susceptible to biodegradation are unlikely to reach the geosphere as they are unlikely to remain stable as they travel through the near field. For example, the pH conditions outside the container walls are expected to be near neutral and will support the microbial activity that will rapidly degrade the complexants. We therefore do not consider that it is proportionate to extend the controls on Category 1 complexants beyond those that are implemented in the current WAC, noting that bulk disposals of these complexants are already prohibited.

Conversely, higher pH conditions generally reduce the ability of EDTA to affect contaminant transport processes as EDTA complexation is weaker due to competition with increasingly stable metal hydroxide species. Chemical speciation modelling indicates that, at pH 12.5, EDTA does not significantly influence the solubility or sorption of contaminants, even when conservative estimates of expected porewater concentrations of the ligand are used [67]. However, we do not propose to alter the WAC conditions relating to Category 2 complexants, nor do we propose to change our overall site-wide capacity, so as to err on the side of caution.

### **5.1.2 Ion Exchange Materials**

The majority of the organic ion exchange materials likely to be disposed of at the LLWR are polystyrene resins. These materials are expected to have slow degradation rates. The release of dimethylamine and trimethylamine from anion exchange resins has been identified as of potential significance, but there is no evidence that degradation and release of these products will occur under LLWR conditions or over timescales relevant to the ESC [95].

We currently receive a similar volume of inorganic exchange materials, such as zeolites, as we do organic resins. The main inorganic ion exchange material found in the waste is the zeolite clinoptilolite. Zeolites are expected to be stable in the LLWR environment, although radionuclides may be released from the exchange sites.

The current WAC requirement [71] (§L2.14) to fix ion exchange materials in a solid matrix prior to disposal should continue, the purpose of which is to further retard the slow release of contaminants from sites of ion exchange. No additional requirements are necessary.

### **5.1.3 Superplasticisers**

Superplasticisers comprise organic substances added to cement to improve its rheological properties, in particular to provide good grout penetration throughout wastes during grouting. Previously we used Sikament 10, a vinyl co-polymer based superplasticiser at concentrations of about 0.9%. Sikament 10 was discontinued and in 2013 we started to use Sikament 700, which is a polycarboxylate ether superplasticiser [96]. Manufacture of Sikament 700 superplasticiser has now ceased. We will begin to use the replacement superplasticiser, Visco-Crete 150-PF, at our next grouting campaign. This superplasticiser is also a Polycarboxylate Ether (PCE) superplasticiser but with a different antifoaming agent. As Sikament 700 and Visco-Crete 150-PF have the same polymer they are expected to behave in the same way.

Work has been carried out recently for the UK Geological Disposal Facility programme examining whether the presence of superplasticisers used in the production of grouted wastefoms can enhance mobility of radionuclides and other contaminants from the grout [97]. The results indicated that polycarboxylate ether superplasticisers do not enhance contaminant mobility from the set grout, either at early or later ages. These results are consistent with a larger body of work from both UK and overseas organisations [98] and provide a robust basis for discounting this process as a significant contribution to contaminant release in the repository environment.

Studies on other types of superplasticisers that could be present in concrete or cement wastes that have been or might be disposed at the LLWR showed that the release of superplasticisers into porewater is likely to be limited [95, 99, 100]. This was attributed to the fact that sorption of superplasticisers to the cement matrix reduced their concentration in cement pore water to such low levels that complexation with radionuclides was not significant, and that there remained sufficient sorption sites on the cement surface that they did not become saturated with sorbed superplasticiser.

Overall, superplasticiser is unlikely to be released into porewater at high enough rates or concentrations to adversely affect radionuclide behaviour. Therefore, no restrictions are necessary on the disposal of concrete or cement waste that might contain superplasticisers.

### **5.1.4 Coagulants and Flocculants**

Conventional inorganic coagulants and flocculants (e.g. aluminium sulphate and iron chloride) work primarily by charge neutralisation and forming metal hydrolysis species that precipitate impurities. Their intended function is aggregation rather than molecular complexation. They have the potential to generate low molecular weight weak monodentate complexants (e.g. chloride and sulphate) that do not require control (see Subsection 5.1.5 and Subsection 5.2.3).

Organic coagulants (e.g. polyacrylamide) are gaining popularity. They are unlikely to generate sufficient quantities of degradation products to significantly affect contaminant mobility at LLWR, as per the discussion in Subsection 5.1.6 on non-cellulosic polymers.

### 5.1.5 Low Molecular Weight Ions

Low molecular weight inorganic ions such as nitrates, carbonates, sulphates and phosphates may be present in waste or formed in the repository over time. They may influence biogeochemical conditions in the repository by acting as electron acceptors in microbially mediated redox chemical reactions – see Subsection 5.2.3 for further discussion.

The major ions are generally weak monodentate complexants. The expected porewater concentration of the major ions is taken into account in our determination of the solubility limits and sorption coefficients that are applied to radiological and non-radiological contaminants in our assessment models.

Low molecular weight organic compounds that may be generated from the in-situ degradation of more complex organic materials, such as cellulose, are discussed in Subsection 5.1.8.

There is no requirement to specify WAC to limit the disposals of these low molecular weight ions.

### 5.1.6 Non-cellulosic Polymers

A large variety of polymers are disposed of at LLWR, including polyvinylchloride (PVC) polyesters, nylon, polystyrene, polyethylene, polypropylene, and rubbers such as neoprene and latex.

These polymers all have high molecular weights and have varying degrees of unsaturation (incorporation of double carbon-carbon bonds) and substitutions of heteroatoms (e.g. halogens, nitrogen and oxygen): halogenated plastics contain either fluorine or chlorine; non-halogenated addition polymers contain carbon and hydrogen and are predominantly fully saturated; condensation polymers may contain oxygen or nitrogen atoms; rubbers may be synthetic and halogenated, or natural latex polymers may be partially unsaturated.

All polymers may degrade to release small molecular weight degradation products, some of which may be capable of complexation with radionuclides and other metal ions.

In reference [85], we considered the potential degradation mechanisms these polymers are likely to undergo in the repository environment. We conclude that the degradation rates of the whole range of synthetic polymers, by any mechanism, are unlikely to generate concentrations of complexants in the near field that could result in an increase in radionuclide mobility. No control measures are proposed for such materials.

### 5.1.7 Cellulosic Materials

Cellulosic materials, including paper, cloth and wood, comprise by far the largest source of organic polymers in LLW projected for disposal at the LLWR.

We have revised our near-field conceptual model (see the '*Near Field*' report [6]). We now expect that pH conditions greater than 12.5 will persist in the porewater environment of the grouted wastefrom for the full lifetime of the repository (until the site is disrupted by coastal erosion). Under these hyperalkaline conditions, it is well established that cellulose

undergoes alkaline hydrolysis to generate soluble degradation products. The main product is isosaccharinic acid (ISA), which can form strong complexes with radionuclides and non-radiological contaminants, making them more susceptible to transport away from the near field.

The 2011 ESC concluded that ISA was not of concern to contaminant retention in the vaults because the pH 10 to 11 conditions that were considered at the time, would be less conducive to cellulose degradation by alkaline hydrolysis and because microbial activity was expected to lower ISA concentrations to levels that would have little effect on contaminant transport. An additional implication of the new understanding of near-field pH is that microbial activity in the grouted wastes will not generally occur [101], meaning that ISA produced by cellulose hydrolysis will accumulate in the porewater solution [6].

We have calculated the aqueous concentration of ISA that is expected to develop in each vault, taking account of the inventory of cellulosic materials [102]. The amount of cellulosic waste that we receive is decreasing, principally because these wastes are often ideal candidates for treatment by incineration. Vault 8 has the greatest inventory of cellulosic waste. Vault 9 is projected to contain approximately half of that in Vault 8, and the inventory of future vaults is projected to contain an order of magnitude less [4].

We have also developed appropriate solubility enhancement factors and sorption reduction factors [102] to represent the effect that ISA has on contaminant mobility in our assessments [15, 16]. ISA forms its most stable complexes with tetravalent species such as plutonium, thorium and technetium.

Our groundwater assessment has been parameterised to reflect our understanding of this process and the associated uncertainty. Therefore, the safety case now takes account of the impact of ISA generated from disposals of cellulosic materials. The potential for enhanced contaminant transport by ISA is reflected in the new radiological and non-radiological capacities that we have set.

We do not consider it necessary to limit the cellulosic content of waste via the WAC because receipts are low and we expect them to decrease further. We monitor the quantity of cellulosic materials that we have received in consignments each year in our ESC Annual Review. We would take action should we observe a significant departure from the projected material composition of future waste arisings that underpin our safety case.

Our near-field modelling shows that degradation of cellulose to produce acidic species, such as ISA, is unlikely to significantly affect the pH of the porewater inside containers because it is insufficient to overcome the hyperalkaline conditioning afforded by the grout, even on a local scale [6] (§6). Departure from the average pH conditions of the wasteform is relevant to contaminant release because it affects the solubility limiting phases and sorption affinity of contaminants. We account for a degree of heterogeneity in the conditions of interest in our ESC assessments.

### **5.1.8 Putrescible Materials**

Putrescible materials are much less common in LLW than in domestic or more general wastes, and are limited by the requirement of the WAC, to not exceed 1% of the internal volume of the disposal container [71] (§L2.15). This constraint originates primarily from a consideration of TPV.

The disposal of putrescible materials is not regarded as detrimental to the performance of the LLWR, in terms of degradation products or the increased release of contaminants. Similar degradation products are formed from cellulose, for example, which do not result in very hazardous or persistent material, by virtue of their biological origin [67]. An exception to this is the generation of ISA, the effect of which we now account for in our ESC assessments, as discussed in Subsection 5.1.7.

Some low molecular weight organic complexants, such as acetate and formate, are seen to accumulate in conventional landfills as the result of the degradation of putrescible wastes. These volatile organic compounds have the potential to form generally weak complexes with contaminant species. They are generally formed in the 'acidogenic phase' by the action of micro-organisms on complex organic molecules present in putrescible waste: proteins, carbohydrates, lipids and nucleic acids. The elevated pH of the grouted wasteform is expected to suppress microbial activity such that these complexants will only be generated in localised niches where the pH may be lower. The low concentrations and relative instability of the complexes they form means that the volatile organic compounds are unlikely to be detrimental to repository performance through their action as complexants.

They may also influence biogeochemical conditions in the repository by acting as electron acceptors in microbially mediated redox chemical reactions, however, are again unlikely to have a significant impact owing to the relatively small quantities generated.

No change is considered necessary to the current limit of 1% of the internal volume of the disposal container for putrescible materials.

## **5.2 Other Substances**

### **5.2.1 Non-aqueous Phase Liquids**

Some waste in the UKRWI destined for the LLWR includes organic substances such as oils and solvents that have limited miscibility with water. Collectively, these liquids can be termed non-aqueous phase liquids (NAPLs). NAPLs are currently subject to certain restrictions within the WAC in that they must be conditioned before disposal and subject to leach tests [71] (§L2.7). This is partly a requirement to ensure compliance with the Consent to Discharge for the site that requires the discharges to be free of visible oil or grease [103]. We have also considered the potential of such substances to increase the migration of associated radionuclides or non-radiological contaminants through buoyancy effects leading to transport rates that exceed groundwater transport rates.

There is some indication that NAPLs may partition some radionuclides into the non-aqueous phase, yet the effect on radionuclide sorption appears to be minimal. NAPL-mediated radionuclide transport is unlikely to have a major effect on travel times from the LLWR through the geosphere and microbial degradation is likely to reduce any effect of NAPLs [95].

There is no evidence to suggest that the disposal of NAPLs will affect the biogeochemical evolution of the repository or the mobility of radionuclides. We have concluded that the requirement for conditioning of such materials prior to disposal is a sufficient requirement to provide reassurance on this aspect.

### **5.2.2 Powders and Colloids**

In the 2011 ESC, consideration was given to the potential for colloids to enhance radionuclide mobility. Colloids<sup>10</sup> might arise from disposed powders<sup>11</sup> or might arise from other colloid-forming wastes, for example, as a result of chemical reactions. They could enhance radionuclide mobility.

Studies on the behaviour of colloids in the trenches and geosphere at the LLWR concluded that colloids and particulates do not play a significant role in radionuclide transport [104]. A similar conclusion was also drawn in terms of the potential influence of particulates and colloids within the vaults.

We have given further consideration to colloid behaviour within the near field since earlier assessments. We have adopted a structured conceptual framework, referred to as the 'colloid ladder'. This decision-tree methodology enables a systematic evaluation of the potential significance of colloids in radionuclide transport, by considering key factors such as colloid stability, mobility and interactions with contaminants under evolving near-field conditions [65].

Recent developments in our understanding of vault performance have led to two notable refinements. Firstly, enhanced cap integrity is now expected to substantially reduce infiltration for several centuries following closure. Secondly, it is now recognised that highly alkaline conditions will persist within grouted containers. These developments underpin the conclusion that colloids are unlikely to play a significant role in the migration of contaminants from the vaults.

The extreme chemical environment and physical constraints imposed by the engineered system are key factors limiting colloid mobility and stability. The porewater within the grout is characterised by a very high pH (greater than 12.5) and elevated ionic strength. These conditions are known to promote colloid coagulation and deposition, thereby reducing the likelihood of colloid persistence in suspension. Laboratory studies have confirmed that

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<sup>10</sup> Colloids are particulates, with diameter between 1 µm and 1 nm, which are suspended in a dispersing medium [152].

<sup>11</sup> Powders comprise solid particles with diameters of less than 1 mm.

calcium concentrations typical of cementitious systems accelerate colloid destabilisation, leading to a progressive reduction in colloid inventories over time.

Furthermore, the fine pore structure of the grout matrix effectively inhibits colloid movement. Potential pathways for colloid transport are limited to the presence of cracks, which would require saturated conditions to become active. Such conditions are not anticipated until failure of the geomembrane, which is not expected to occur until at least 500 years after closure, and more likely after 1,500 years. Even in the event of such failure, colloids formed at external corrosion sites, such as iron oxides or sulphides, are expected to have limited interaction with radionuclides present in the waste, thereby reducing their relevance to safety assessments.

In summary, some disposed materials could give rise to colloids, and the relevant materials are significant in the inventory. However, we conclude that colloids will not significantly enhance contaminant release from the vault near field and we have not identified any practical controls that could be implemented to limit such disposals. Rather, our approach focuses on monitoring and assessing the potential effects of colloids.

While it is acknowledged that some colloids may persist under geosphere conditions where chemical environments differ from those in the near field, their contribution to radionuclide transport is expected to be negligible in comparison to dissolved-phase mechanisms.

### **5.2.3 Nitrates and Sulphates**

Of the remaining substances that are relevant to the 'other materials' category in the UKRWI, nitrates and sulphates are present in several waste streams and have the potential to influence the biogeochemical conditions within the vaults. They form soluble or weakly soluble salts and could influence biogeochemical processes in niches where the pH is below 12.5. In most wastes, the grout maintains a pH that restricts microbial processes.

On the basis of analyses of the geochemical evolution, the effect of nitrate will be minimal [6]. The presence of sulphate in the waste may be beneficial, however, in the case that microbial sulphate-reduction occurs in the lower-pH gaps between the containers. Some non-radiological contaminants, such as lead, mercury and cadmium, have very low solubility in the presence of sulphide, thus conditions in the gaps could enhance their retention.

There is no requirement to specify WAC to limit the disposals of either nitrate or sulphate.

## 6 Controls to Limit Radiological Inventory

A principal component of WAC is the setting of radiological limits relating to the quantities and concentrations of radionuclides that can be disposed of in a facility. The objective of this section is to define the controls to limit the radiological inventory to ensure regulatory criteria are met. The results of the various assessment cases<sup>12</sup> that have been developed for the 2026 ESC are used to develop these limits. This includes:

- limits on total activity in the repository (referred to as 'radiological capacities');
- limits on activity in individual consignments;
- limits on average activity concentration in a consignment (referred to as 'activity concentration limits');
- limits we use to determine emplacement locations of certain consignments (referred to as 'emplacement limits');
- activity limits at a sub-container scale including controls on discrete items (including sealed sources) and active particles; and
- limits for fissile radionuclides.

The sum-of-fractions approach is based on derivation of values of radiological limits for each assessment case and for each radionuclide. The radiological limit for radionuclide (n) is the activity or activity concentration (as appropriate for the assessment being considered) at which the peak impact from that radionuclide alone would be equal to the appropriate regulatory criterion. In order to limit the total impact from all radionuclides such that it does not exceed the regulatory criterion, the following summation is required:

$$\sum_n \frac{I_n}{L_n} \leq 1 \quad (6.1)$$

where  $I_n$  is the disposed activity or activity concentration of each radionuclide and  $L_n$  is the radiological limit.

To ensure regulatory criteria are met:

- total disposals to a facility must be such that the sum-of-fractions values for each assessment case are less than one; and

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<sup>12</sup> An assessment case is defined in the ESC as a specified combination of events, circumstances, conditions or their evolution, including specification of model boundary conditions and data, which represents a particular realisation of the disposal system, its evolutions and radionuclide or contaminant release, migration and exposures.

- activity concentration levels at the relevant spatial scale must be such that the sum-of-fractions values for each assessment case based on activity concentration are less than one.

This approach to setting limits on the total quantities and activity concentrations of radionuclides is set out by the IAEA in their *"Derivation of Activity Limits for the Disposal of Radioactive Waste in Near Surface Disposal Facilities"* report [33]. The sum-of-fractions methodology is also applied in EPR 16 when determining if radioactive waste is out of scope of legislation [21] (§Schedule 23).

Radiological limits are given in terms of total activities (TBq) or activity concentrations (GBq t<sup>-1</sup> or GBq m<sup>-3</sup>). For radionuclides that decay to unstable isotopes, radiological limits are based on the quantity of disposed activity including the summed impacts of the parent and all daughter radionuclides.

Radiological limits can be derived for an appropriate range of assessment cases. The limits are generally derived based on the assessment results for the time of peak assessed impact for each radionuclide<sup>13</sup>. The results are expressed in terms of potential annual doses or risks to potential representative persons. Peak impacts from different radionuclides may occur at different times (for example, due to different sorption characteristics within the groundwater pathway). The sum-of-fractions approach sums peak impacts irrespective of time of occurrence and is thus cautious in such cases.<sup>14</sup>

An example of the sum-of-fractions approach, for a single assessment case, is given in Box 6.1.

**Box 6.1: Example hypothetical use of the sum-of-fractions methodology.**

This example is based on a simple inventory for a hypothetical disposal facility for the four radionuclides given below plus additional radionuclides that have lesser impacts per unit quantity of activity disposed. The radiological capacities for the hypothetical facility are based on an assessment case in which leached activity enters groundwater, which is extracted for irrigation resulting in doses to an appropriate exposure group, such as a farming family. The radiological capacities are the quantity of each radionuclide that alone would give rise to a peak impact equivalent to the appropriate regulatory criterion, for example a risk of 10<sup>-6</sup> per year.

Application of the sum-of-fractions methodology requires dividing the inventory of each radionuclide by its radiological capacity, summing the resulting values and ensuring that the sum of the contributions is less than 1.

<sup>13</sup> Exceptions exist for the Period of Authorisation assessment, discussed separately

<sup>14</sup> Exceptions exist for certain combinations of exposure pathways as discussed in Section 11 of the Long-term Radiological Impacts report, but these are either of low likelihood or consequence

**Table 6.1: Example application of the sum-of-fractions methodology for a hypothetical radionuclide inventory.**

Radionuclide	Inventory (TBq)	Radiological Capacity (TBq)	Contribution to sum of fractions
C-14	2	10	0.2
Ru-106	100	50,000	0.002
Cs-137	30	3,000	0.01
U-238	0.1	2.5	0.04
Others	50	1,000,000	0.00005
Total			0.25

In this example, the highest inventory is for Ru-106 but, due to its relatively short half-life and slow rate of transport in groundwater, it has a relatively high radiological capacity and its contribution to the sum of fractions is therefore small. In contrast, C-14 has a much lower inventory but its impact per unit of activity for this assessment case is much greater because of its unretarded transport in groundwater and subsequent uptake in foodstuffs. C-14 therefore makes the largest contribution to the sum of fractions. Cs-137 is intermediate between Ru-106 and C-14 in terms of inventory and radiological capacity, and therefore in its contribution to the sum of fractions. U-238 is the second most significant radionuclide, despite having the lowest inventory, due to its relatively low radiological capacity. The role of the capacity for other radionuclides is discussed further in Subsection 6.2.

The total sum of fractions is 0.25, demonstrating that the sum of the impacts from these radionuclides for this assessment case is equivalent to about a quarter of the regulatory criterion, that is their combined impact is no more than a risk of about  $2.5 \times 10^{-7}$  per year.

Derivation of radiological capacities is presented in Subsection 6.3, derivation of activity concentration limits and emplacement limits is presented in Subsection, 6.4 and derivation of sub-container scale controls is presented in Subsection 6.5. Firstly, however, consideration is given to the approaches adopted for the selection and treatment of the assessment cases to be used in deriving limits (Subsection 6.1) and to the selection of radionuclides for which individual limits are appropriate (Subsection 6.2). Controls on fissile material are discussed in Subsection 6.6.

We discuss whether additional controls would be required if a decision was taken to accept ILW in each subsection.

## 6.1 Selection of Assessment Cases

The first step for deriving limits is the selection of appropriate assessment cases and identification of the appropriate regulatory constraint, limit or guidance level. Consideration is also given to the scale at which subsequently derived limits are applicable. It is important, at this stage, to ensure that an appropriate set of assessment cases has been identified.

For the 2026 ESC, new assessments have been undertaken [64, 105, 106, 107, 108] and have all been aligned with our Assessments Manual [109].

The assessment calculations consider potential impacts that may occur both during the PoA [14] and thereafter [15]. We have considered a range of assessment cases in terms of different release and exposure pathways and different times of potential exposures corresponding to different site evolutions or different times of human intrusion. The selection of assessment cases for use in defining controls is discussed further in Subsections 6.1.1 to 6.1.5.

For each of the selected assessment cases, the relevant regulatory criterion also needs to be identified. These are based on our interpretation of the criteria given in the GRA [20] and in supplementary groundwater guidance issued by the Environment Agency [110]:

For the PoA, the relevant annual dose criteria are:

- 0.3 mSv from any source [20]; and
- 0.01 mSv through the groundwater pathway, or if this is exceeded, then less than 0.3 mSv through all pathways with a requirement that doses are as low as reasonably achievable, economic and social factors being taken into account [110].

After the PoA, the principal criteria used are:

- the risk guidance level of  $10^{-6}$  per year; and
- for human intrusion and deliberate interaction with waste following coastal erosion, the annual dose guidance level range of 3 mSv for exposures continuing over a period of years and 20 mSv for short-term exposure.

These are taken to apply to all waste disposed at the site and any waste to be disposed in future, considered collectively as a single source.

During the PoA, members of the public could be exposed by multiple pathways simultaneously. The GRA requires that exposure from all relevant pathways is assessed. We assess doses to 'representative persons', taking into account all pathways to which they could be exposed based on their habits [14]. Doses from each pathway are calculated separately and doses from all relevant pathways are summed to calculate total dose to a given representative person. Some doses during the PoA depend on the total activity in the repository or in open vaults, and others depend on activity concentration in the waste. We have therefore considered which pathways may require specific controls independently, as discussed in Subsection 6.1.5. In some cases, controls to limit impacts during the post-PoA

will also ensure that impacts during the PoA are below the dose constraints. As we have used capacities based on post-PoA impacts to inform our discussion of potential capacities based on PoA impacts, we present consideration of PoA impacts after those for the post-PoA period.

For the period after the PoA, we consider that the relevant cases for consideration in establishing total capacities are generally those assessment cases that are the most representative of each pathway. We do not consider impacts from multiple pathways because the probability of such multiple exposures is low (see reference [15]).

Whilst we generally choose the reference case from each assessment for setting limits, we also consider the range of uncertainty cases to arrive at the most appropriate basis. It may be appropriate to depart from the reference case where an uncertainty represents a 'tipping point' in overall impacts. An example of this approach is in our consideration of capacities from the gas pathway, where we adopt a cautious consideration of the lifetime of the geomembrane (Subsection 6.3.2).

Having identified the appropriate assessment cases, radiological limits can be derived for each radionuclide considered. At this stage, as shown in Subsections 6.3 and 6.4, it is sometimes possible to demonstrate that some assessment cases are less restrictive than others for all radionuclides. When this applies, attention can be focused on the more restrictive assessment cases as a basis for deriving limits.

It is important to consider, for each assessment case taken forward as a basis for deriving limits, whether the impacts depend primarily on the total inventory (TBq) for each radionuclide or whether impacts are related to radionuclide concentrations (GBq t<sup>-1</sup>). We have identified limits that we will apply to:

- total activity levels at the scale of the vaults or the site;
- waste consignments;
- activity concentration at a sub-container scale.

In deriving radiological capacities, which are total activity limits, we have also considered how best to address the impacts from disposals to the trenches, past disposals to Vault 8 and 9 and future disposals to Vault 9 and future vaults. We consider whether radiological capacities should be defined for the vaults as a group, including the existing disposals to Vault 8 and 9, or if capacities should be defined only for future disposals, with disposed inventory accounted for as part of derivation of the capacities. We also consider whether radiological capacities should apply to the activity summed over all vaults or whether limits for the vaults need to be sub-divided, for example to set limits for each vault or per year.

For those assessment cases for which impacts depend on the total levels of activity, it is necessary to consider if contributions from the trenches and vaults are additive, or whether such contributions are independent of each other. For those cases for which trench and vault impacts are additive, the derivation of radiological capacities for vault disposals needs to take account of the disposals to the trenches and their impacts.

The ESC also considers doses to non-human biota [17]. However, we consider that these impacts are not an appropriate basis for setting WAC or emplacement controls. Unlike for people, there is no regulatory dose or risk criterion that could be used as the basis for WAC or emplacement controls. If we were to derive our own criteria, we would have to derive a different dose rate criterion for each representative organism. All significant pathways by which biota may be exposed are also considered in the assessments of impacts to people and, therefore, in the WAC and emplacement controls derived from these assessments. We consider that these WAC will also be sufficient to protect populations of biota. During the PoA, biota may be in different locations to members of the public and may be more significantly exposed to radiation. However, these exposures will be localised and are unlikely to threaten populations of biota. Therefore, they would not have detrimental effects on populations of biota and additional WAC or emplacement controls are not required.

### **6.1.1 Gas Assessment**

After the PoA, only C-14 and Rn-222 are of potential importance in terms of potential gaseous releases [111]. The appropriate criterion in this period is the risk guidance level of  $10^{-6}$  per year.

Given the current uncertainty in bulk gas generation rates, we have not yet decided whether to close the vent or leave it open at the end of the PoA. Radiological capacity cases with the vent closed and the vent left open were therefore assessed. Additionally, whilst it is likely the geomembrane would be intact when the repository starts to be disrupted by coastal erosion, it is also possible it would be degraded. Thus, there is a non-trivial probability that the cap geomembrane would degrade before the repository starts to be disrupted by coastal erosion. In some exposure scenarios, impacts to a receptor are from radon or C-14, but in some exposure scenarios a receptor could be affected by both radon and C-14. We have considered several cases as follows.

With the cap vent closed, and the cap geomembrane intact or degraded, the relevant capacity cases are:

- Exposure to radon gas in houses on the cap.
- Exposure to radon and C-14 gases in smallholdings on the cap.

With the vent left open, and the cap geomembrane intact, the relevant capacity cases are:

- Exposure to radon gas in houses on the vent.
- Exposure to radon and C-14 gases in a smallholding on the vent.

A wide range of smallholding layouts are possible. Therefore, exposure to radon and C-14 gases in a smallholding on the vent is split into three bounding cases.

- A smallholding is on the vent, a house and a kitchen garden are on the vent, radon and C-14 gases.
- A smallholding is on the vent, a kitchen garden is on the vent, but a house is not on the vent, C-14 gas.

- A smallholding is on the vent, a kitchen garden and a house are not on the vent, C-14 gas.

Risks from radon and C-14 gas are highest when the cap vent is closed at the end of the PoA, therefore radiological capacities are derived from cases where the vent is closed at the end of the PoA. The area averaged dose over the whole repository plan area is used to calculate risks to a smallholder or house occupant on the cap. These risks take account of the probability that a smallholding or house is located on the cap. The calculated risks from C-14 bearing gas increase substantially when the cap geomembrane fails. The calculated risks from radon are higher when the cap geomembrane is intact. We undertook a deterministic approach in deriving the capacities for each case, rather than assigning probabilities to the geomembrane failure times.

We have based our capacity for C-14 bearing gas on a deterministic case in which the geomembrane fails at a relatively early time. This is cautious. The capacities are derived on the scale of the vaults as a whole.

Combined impacts from radon and C-14 must be considered, as both can affect a smallholder on the cap. As existing disposals of Ra-226 affect the capacity for C-14 and vice versa, we have calculated the risk from both radionuclides in waste disposed to date. We have subtracted this risk from risk guidance level and used the residual 'risk budget' to calculate the remaining capacities for future disposals. Peak impacts from radon occur prior to failure of the geomembrane and peak impacts from C-14 occur afterwards. However, we have cautiously taken the risk from a unit inventory prior to geomembrane failure for radon and the risk from a unit inventory after geomembrane failure for C-14 when deriving remaining capacity for each radionuclide.

The radiological risk from the C-14-bearing gas and radon gas pathways are proportional to the total inventories of C-14 and Ra-226 respectively. Heterogeneity in the spatial distribution of the inventory leads to heterogeneity in potential doses to people living on the cap. The potential for heterogeneity in doses is much greater for radon than C-14 gas. With the cap geomembrane intact, most of the radon flux to a house located over a defect (small hole) in the geomembrane comes from the container immediately below the defect and the immediately adjacent containers. Limits on the amount of Ra-226 in a container can be used to control heterogeneity in the potential doses to people living in houses on the cap, and therefore the highest potential doses.

The gas assessment results are used to consider consignment emplacement limits for future disposals of Ra-226 to the vaults and radiological capacity for future disposals of C-14 and Ra-226 to the vaults.

### **6.1.2 Groundwater Assessment**

For releases to groundwater, the impacts after the PoA are assessed in terms of the calculated risks to representative persons by a well pathway, a stream pathway, an estuary pathway and a marine pathway.

- The well pathway considers the use of groundwater by domestic households directly for drinking water, for irrigation to support growing fruit and vegetables and for use by hens kept for egg production.
- The stream pathway assumes that overtopping occurs leading to overland flow of contaminated water to Drigg Stream. Exposure to contaminated stream water and land (stream bank), and consumption of food products from cattle that graze on the stream bank are considered.
- The estuary pathway considers exposure to contaminated estuary pasture and salt marsh regions, and seafood products obtained from either the estuary waters or sediments. The estuary contamination includes radionuclides entering the Irt Estuary from Drigg Stream (if overtopping occurs) and from water and sediment exchange with local coastal waters and sediments.

The stream pathway is treated very cautiously in the assessment model as it assumes that:

- overtopping occurs and that the overtopping water is equilibrated with the pore water of the waste;
- all overtopping water can enter the stream, with no account taken of water that may percolate vertically through the topsoils and enter the groundwater;
- all activity can enter the stream, which neglects the possibility that activity may be deposited on soils and vegetation between the repository and the stream;
- there is no association of activity with suspended sediments in the stream water, which will lead to an overestimate of the stream water activity concentration;
- porewater of stream bank soils contains the same radionuclide concentrations as stream water.

Discharges to the stream only occur in a small number of realisations [15, 64]. These cautions mean that the expectation value of the risk is dominated by a small number of high impact realisations, which is characteristic of a skewed distribution of assessed risks. Given these considerations, we do not judge the stream pathway an appropriate basis for the setting of capacities.

In general, the risk from the estuary pathway is dominated by contributions from the stream. As noted above, the stream contribution is unduly cautious for setting capacities. There is a period from 2200 AD to 2550 AD when the assessed risks from the estuary pathway are dominated by contributions from the marine environment. Risks from the marine pathway are higher than those from the estuary pathway during this period. The marine pathway risks will therefore bound the marine contribution to the estuary pathway. Given these considerations, we do not consider the estuary pathway to be an appropriate basis for setting capacities.

On this basis, we consider the well and marine pathways as a basis for deriving radiological capacities for the groundwater pathway.

The appropriate criterion for deriving radiological capacity values is the risk guidance level of  $10^{-6}$  per year.

Impacts result from releases from both the trenches and vaults, so their combined effects must be considered when establishing radiological capacities. Similarly, there is no clear rationale to impose restrictions on individual vaults; therefore, we use the assessment to determine radiological capacity values for all vaults collectively, taking account of existing trench disposals.

### **6.1.3 Human Intrusion Assessment**

For human intrusion assessment events [108], doses are assessed for representative persons associated with an intrusion event, for example to a borehole driller, and for representative persons who are assumed to be exposed to waste previously excavated, for example a smallholder living on land contaminated by a prior intrusion. This assessment also considers deliberate scavenging<sup>15</sup>, seeking out, interacting with and collecting of waste items (including discrete items) and repository materials that have been exposed as a result of coastal erosion (although these events are not considered to be human intrusion). These events are distinct from exposures arising from casual encounters (which are addressed in the coastal erosion assessment, discussed in Subsection 6.1.4. Additionally, this assessment considers inadvertent exposure to particles as a consequence of human intrusion.

The assessed effective doses to intrusion representative persons should not exceed an annual dose guidance level in the range of around 3 mSv to around 20 mSv. Values towards the lower end of this range are applicable to prolonged exposures over several years or a lifetime (e.g. the site occupier), while values towards the upper end of the range are applicable to short term exposures (e.g. the borehole driller).

For all these events, the potential impacts are determined by the activity concentration in waste brought to the surface during intrusion or exposed during coastal erosion. Given the limited areal extent of potential intrusions from the cap surface, and that coastal erosion of the vaults and trenches is expected to occur sequentially, the assessed events for the trenches and vaults are considered to be independent of each other and therefore we do not need to consider potential additivity of impacts between the trenches and vaults. The results are therefore used to consider consignment activity concentration limits for future disposals to the vaults, and limits on waste at a smaller scale (such as items and particles).

In our assessment, we assume that human intrusion could occur from the end of the PoA. We cautiously assume that deliberate interaction with waste following coastal erosion (e.g. material recovery) could occur from 300 years after disposal although this is before the estimate of the earliest possible exposure by coastal erosion<sup>16</sup>. Activity concentration limits

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<sup>15</sup> We only assess inadvertent intrusion - the scavenger is assumed to have no knowledge of the nature of the site but scavenges waste items because they look interesting.

<sup>16</sup> The 300-year baseline has been chosen for calculations of limiting radionuclide concentrations. This cautious approach is used for calculating limiting activity concentrations that will inform the WAC and emplacement

are calculated at several different dates for each assessment event as doses will be higher at different times for different radionuclides, depending on their decay chain. When identifying potential controls based on human intrusion or deliberate interaction with waste following coastal erosion, for each assessment event we have used the most restrictive limit for each radionuclide across the following times after disposal:

- events not involving coastal erosion: 100, 300, 1,000, 5,000 yr after disposal; and
- events involving coastal erosion<sup>17</sup>: 300, 650, 1,000, 1,150, 3,000, 5,000 yr after disposal.

This is cautious, as a single receptor would never be exposed to the peak dose from every radionuclide at the same time. However, this approach enables a single set of activity concentration limits to be identified for each assessment event for comparison against each other to identify the appropriate limits to apply.

#### **6.1.4 Coastal Erosion Assessment**

The coastal erosion assessment considers impacts to representative persons that make use of the local and regional coast for recreational and occupational purposes and those that consume marine foodstuffs [112]. Exposures occur from the dispersion of radionuclides in the environment during the erosion of the vaults and trenches. For this situation, we have estimated conditional risks because people are expected to be exposed to waste and associated radionuclides eroding from the repository. Doses are calculated for comparison against the risk guidance level of  $10^{-6}$  per year, which corresponds to an annual effective dose of 20  $\mu$ Sv assuming exposures occur. Deliberate scavenging, seeking out, interacting with and collection of waste items and repository materials is considered separately, as discussed in Subsection 6.1.3.

For the reference case the erosion front is orientated parallel to the long axis of the vaults and trenches (approximately swash aligned) and assumes no preferential erosion. Variant cases consider oblique erosion but our assessment shows that peak doses are not significantly sensitive to the orientation of the erosion front [107]. On this basis, the impacts from the vaults and trench are largely independent because the peak impacts from the vault waste will occur prior to the trenches beginning to erode.

Assessment calculations also show that the results are not particularly sensitive to how the LLW inventory is distributed between the different vaults. Because of this, the assessment does not need to consider each vault separately when deriving safety limits. Instead, it treats the vaults collectively as a single group for the purpose of setting radiological capacity values. This approach simplifies the assessment and ensures that the derived limits are

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controls. This is because limiting radionuclide concentrations may affect individual waste acceptance decisions; it is harder to accommodate potential future changes that affect individual waste consignments than other controls on repository safety (such as overall capacity limits).

<sup>17</sup> We do not consider deliberate interactions with waste exposed via coastal erosion or inadvertent encounters with particles as "human intrusion". However, it is considered appropriate to apply the same assessment criteria as with human intrusion events, namely the annual dose guidance level range of around 3 mSv to around 20 mSv.

protective, regardless of how the radionuclides might be distributed across the vaults in future disposals.

### 6.1.5 Period of Authorisation Assessment

During the PoA, members of the public could be exposed by multiple pathways simultaneously. The GRA requires that exposure from all relevant pathways is assessed. We assess doses to 'representative persons', taking into account all pathways to which they could be exposed, based on their habits [14]. Doses due to gaseous releases, releases in leachate to the marine environment (via the marine pipeline), to surface water systems and to groundwater, and external irradiation are assessed [14]. Total doses are calculated for representative persons, taking into account which pathways they could be exposed to. The appropriate regulatory criterion for total annual dose is the 0.3 mSv dose constraint.

Doses for specific pathways present during the PoA can be a function of the total disposed activity in the repository, activity disposed in part of the repository or activity concentration in wastes (see Table 6.2).

**Table 6.2: Summary of activity parameter used to calculate dose for each pathway during the PoA**

Pathway	Activity or concentration dose is dependent on:
External	Activity concentration in conditioned waste in uncapped vaults only
Groundwater	Total activity in the whole repository
C-14 bearing gas	Total activity in the whole repository
Radon	Total activity in the whole repository
Tritium bearing gas	Total activity in any vaults and areas of the trenches not covered by the final cap
Leachate to sea	Total activity in any vaults and areas of the trenches not covered by the final cap, excluding waste in warehouses

As a consequence, it is not straightforward to derive a single and simple set of controls based on potential impacts during the PoA. A constraint would need to be defined for each pathway such that the total dose from all pathways could never be more than the source-related annual dose constraint of 300  $\mu$ Sv. Some pathways lead to significantly higher doses than others during the PoA, as discussed in reference [14]. As such we do not think it would be proportionate to derive controls for all pathways. We have therefore considered each pathway in Subsections 6.1.5.1 to 6.1.5.5 to establish which pathways may require specific controls.

Doses due to contamination in the Drigg Stream from permitted historical discharges are also assessed in the PoA assessment, however the representative persons are not exposed via this pathway as their habits do not include use of water from the Drigg Stream. Although discharge to the Drigg Stream remains a permitted route, we would only make use of it in exceptional circumstances, such as an extreme storm. Peak dose as a result of exposure following a storm event was calculated to be 1.7  $\mu\text{Sv}$  for the reference inventory. We therefore do not consider this pathway when considering capacity controls due to the low likelihood of occurrence and low calculated doses compared to the dose criterion of 300  $\mu\text{Sv}$ .

#### **6.1.5.1 External irradiation**

External doses from disposals to the trenches are negligible because the trench cap attenuates gamma radiation from trench wastes. Similarly, once vaults are covered by strips of the final cap, external doses will be negligible. Therefore, only containers in uncapped vaults need to be considered.

External irradiation doses are dominated by the concentration of key gamma emitting radionuclides, in particular Co-60 and Cs-137. The potential need for controls based on activity concentrations in future wastes requires consideration, in particular for containers in direct line of sight of an offsite receptor and at the top of stacks.

#### **6.1.5.2 Groundwater**

Future disposals will all be to the vaults, the vast majority as containerised, conditioned waste. During the PoA, releases from the vaults will be negligible. This is because:

- Prior to the cap being installed, the vaults act to contain leachate and direct it to the leachate management system. There is no evidence of contamination in the groundwater arising from the vaults.
- Once the cap is installed, water flows into the vaults (and hence releases from the vaults) will be very low as a result of effective cap performance.

On this basis, it is unnecessary to limit disposals to the vaults based on impacts from the groundwater pathway during the PoA.

The impacts from releases to groundwater during the PoA are therefore determined by inventories associated with past disposals to the trenches. For the groundwater pathway, it is therefore appropriate to derive radionuclide limits on the basis of calculations for the post-PoA period only, as discussed in Subsection 6.1.2.

#### **6.1.5.3 C-14-bearing gas**

As discussed in Subsection 6.3.2, we propose to operate to a revised C-14 capacity of 14.5 TBq until the strengthened container is implemented based on our assessment of impacts from the C-14-bearing gas pathway for the post-PoA period.

The peak total dose to the representative person from the C-14 bearing gas pathway during the PoA was assessed to be  $6.9 \times 10^{-3} \mu\text{Sv}$  from the Stage 2 Reference Inventory<sup>18</sup>. This is trivial in comparison to doses from other exposure pathways during the PoA.

This peak assessed dose during the PoA occurs in 2036, when the total C-14 activity disposed is 13.7 TBq (excluding C-14 in wastes disposed to date). Under the proposed controls for C-14 before the strengthened HHISO is implemented, no more than 14.5 TBq could be disposed by this date, therefore doses could not be significantly higher than calculated in the model and would remain insignificant in comparison to other pathways.

On this basis, we are not proposing to define a capacity for C-14 bearing gas based on the PoA assessment. This position will be revisited when we re-derive post-closure capacities, as discussed in Subsection 6.3.2.

#### **6.1.5.4 Ra-226 leading to radon gas**

The peak dose from the radon gas pathway during the PoA was assessed to be  $6.2 \mu\text{Sv}$  based on the Stage 2 Reference Inventory. Ra-226 in wastes disposed to the trenches (0.29 TBq) and Vaults 8 and 9 (0.11 TBq) is the main contributor to this dose.

As discussed in Subsection 6.3.2, we propose to operate to a revised Ra-226 capacity of 0.04 TBq based on our assessment of impacts from the radon gas pathway for the post-PoA period. This capacity applies to future disposals of Ra-226 only. The total Ra-226 activity associated with future disposals is 0.029 TBq in the Stage 2 inventory and  $6.8 \times 10^{-3}$  TBq in the Stage 3 inventory. Both of these values include all LLW forecast to be sent to the LLWR and some ILW. Therefore, even if the total amount of radon disposed in future vaults was equal to the proposed radiological capacity, wastes disposed to date in the trenches and Vault 8 and 9 would still dominate radon dose during the PoA. We are therefore not proposing to define a capacity for Ra-226 based on the PoA assessment. If the Ra-226 capacity based on the post-closure gas assessment were to be revised in future, this position would need to be revisited.

#### **6.1.5.5 Tritium in water vapour and marine discharges**

Tritium in water vapour arises from evaporation of tritium-bearing leachate in the trenches and tritium bearing porewater inside containers in the vaults. Average trench leachate concentration data are used to represent the current concentration of tritium in both trench leachate and vault waste porewater (see reference [105]). In the assessment model, future leachate concentrations are calculated based on the ratio of current to projected inventory and are input into the calculation of fluxes. We assume that only facilities not covered by the final cap contribute to the release of tritiated water vapour, as it is expected that the final cap will significantly reduce infiltration and hence reduce the amount of leachate that could be

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<sup>18</sup> The inventory for the 2026 ESC was derived using an iterative process. We have used three different inventories, referred to as Stage 1, Stage 2 and Stage 3 Inventories, during the ESC development. Our approach to inventory development is described in reference [4].

lost via evaporation. Any controls would therefore apply to waste in areas of the repository not covered by the final cap.

As tritium has a half-life of just over twelve years, it does not give rise to significant impacts in any of the post-PoA assessments. It is therefore necessary to consider whether tritium should be controlled on the basis of potential impacts during the PoA. Tritium is also present in leachate discharged via the marine pipeline, therefore combined impacts from aerial and marine releases need to be considered.

Permitted discharge of leachate is made via the marine pipeline. Leachate generated in the vaults and trenches is collected and combined prior to discharge, therefore impacts via the marine pathway depend on both vault and trench wastes. The leachate contains a mixture of radionuclides, including tritium.

In the assessment model, future leachate concentrations are calculated by scaling current average leachate concentrations (calculated based on monitoring data) from the vaults and trenches. The concentrations for the monitored radionuclides are scaled based on the ratio of current trench and vault inventory of those radionuclides to the projected inventory that could contribute to leachate generation. Only wastes in areas of the trenches not covered by the final cap and wastes in uncapped vaults (excluding waste in warehouses) are modelled as contributing to generation of leachate that is subsequently discharged. This is because the final cap and the protection of warehouses will significantly reduce the amount of rainwater that could come into contact with waste to generate leachate. No account is taken of the southern trenches interim cap replacement, which will reduce leachate generation from the trenches.

Our assessment results indicate that tritium released in water vapour is not a significant contributor to dose during the PoA based on the Stage 2 reference inventory [105]. In the reference case, the peak annual dose to the representative person from tritium (including inhalation and ingestion of contaminated foodstuffs) is 0.67  $\mu\text{Sv}$ .

Similarly, impacts from release of leachate via the marine pipeline are not a significant contributor to total dose during the PoA based on the Stage 2 reference inventory. The peak annual dose from marine discharges in the reference case was 1.6  $\mu\text{Sv}$  to a fishing family receptor, with dose dominated by consumption of marine foodstuffs. C-14 is the main contributing radionuclide to total dose from marine discharges. The peak annual dose from marine discharges to the representative person was 0.49  $\mu\text{Sv}$ , with all dose due to consumption of marine foodstuffs (the representative person does not spend time on the beach).

The combined dose to the representative person from the marine and tritium in water vapour pathways is just under 0.4% of the annual dose criterion (300  $\mu\text{Sv}$ ). The Stage 2 reference inventory includes all LLW that is projected to be sent to the LLWR according to the 2022 UKRWI, and some ILW. It is therefore unlikely that LLW would be consigned such that these pathways became more significant contributors to total dose during the PoA.

Given the low contribution to total dose during the PoA, we believe it would be disproportionate to set vault capacities based on the marine or tritium bearing gas pathways. By taking this approach, we are effectively assuming that there would be no sudden changes between forecast LLW and what waste is actually consigned to the LLWR in future.<sup>19</sup> While this approach assumes continuity between forecast LLW and actual waste consignments to the LLWR, we have measures in place to ensure changes are identified.

- We monitor leachate concentrations in the vaults and trenches quarterly and review monitoring trends annually to identify any changes.
- We monitor waste receipts compared to forecast inventory as part of our annual reviews of the ESC.
- We calculate retrospective doses annually using monitoring data.
- RIFE reports would show any increases in marine concentrations, although these could also be due to releases from Sellafield.
- We routinely assess new information, such as new versions of the UKRWI, for their implications for the ESC. These forward-looking reviews would identify any major changes to the inventory, which we would assess for its implications for the ESC.

During the PoA, leachate will continue to be monitored and discharges controlled as necessary in order to demonstrate and ensure that impacts remain acceptable.

#### **6.1.5.6 Implications if higher activity waste was accepted**

Additional measures may be required to manage dose rates from higher activity waste during the PoA, as discussed in Subsection 6.4.2.2.

If a decision was taken to accept waste with activity higher than the LLW definition of 4 and 12 GBq t<sup>-1</sup>, no additional controls would be required to manage disposal of ILW on the basis of impacts from the groundwater pathway during the PoA. The arguments made for not needing to consider controls relating to the groundwater pathway during the PoA in Subsection 6.1.5.2 are equally applicable to LLW and ILW as they are not dependent on activity.

If a decision was taken to accept ILW for disposal, it might be packaged in a strengthened HHISO or an alternative strong container. As discussed in Subsection 6.3.2, the proposed capacity for C-14 is based on disposal in the current container concept. We would derive a new capacity for C-14 for the strengthened HHISO and for any alternative container, based on the C-14 bearing gas pathway. We would consider whether the new capacities calculated

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<sup>19</sup> We acknowledge that sudden changes could occur – for example, if there were an abrupt halt in waste consignments. However, such changes would not result in negative consequences for the management or safety of the repository, because our control measures emphasise responding to changes that would have meaningful negative consequences.

based on the post-PoA period were sufficient to limit impacts during the PoA or if controls based on PoA impacts would also be required.

If ILW was proposed for disposal that had higher Ra-226 content than was included in the Stage 2 reference inventory, we would need to review whether to change the relative allocation of the gas assessment capacity to Ra-226 and C-14 (see Subsection 6.3.2). We would consider implications during the PoA and whether it was necessary to set a capacity based on impacts during the PoA as part of this.

The arguments set out in subsections 6.1.5.5 for not needing to consider controls for the tritium aerial release pathway and the marine pathway are based on the Stage 2 Reference inventory, which includes some ILW. For both pathways, doses are dependent on wastes in uncapped vaults, as ILW in shielded modules would not contribute to either pathway. If proposed disposals of ILW to a given vault were significantly higher than the activities assigned to each vault in the Stage 2 reference inventory, we would need to review whether this could lead to increased doses. This would be identified as part of managing an optimised plan for ILW disposal (Subsection 8.1.2)

## **6.2 Establishment of Radionuclide Screening Criteria**

We use our Radiological Hazard Index model to select radionuclides of potential importance to the ESC. All radionuclides listed in the UKRWI were assessed in the Radiological Hazard Index model. We used the model to identify radionuclides that contribute to the top 99.9% of dose by any pathway, and assess these radionuclides in our assessments [15, 113].

The assessment cases identified in Subsection 6.1 could be used directly to specify individual limits for every radionuclide considered in the assessments. However, the calculated radiological capacities and activity concentration limits for radionuclides vary greatly depending on their intrinsic significance in each assessment case, independent of their expected inventory in future disposals to the LLWR. Calculated radiological capacities and activity concentration limits for some radionuclides are very large and essentially meaningless in practice. To minimise the complexity of the radiological controls, we use a screening process to reduce the number of radionuclides for which a capacity or limit is specified. We ensure individual radiological capacities and activity concentration limits are only specified for radionuclides that require specific control. Radionuclides that cannot make a significant contribution to peak impacts for a given assessment case are not assigned a radionuclide-specific capacity or limit for that case.

This approach focuses waste management resources on those radionuclides of greatest potential significance and provides a more focused and practicable set of controls. The role of screening is recognised in reference [33] and in previous work carried out for the Environment Agency [114], which notes that *'as it would be impractical and costly to apply and demonstrate compliance with limits for every individual radionuclide, however, it is suggested that individual radionuclide limits should only be applied to those key radionuclides that contribute significantly to post-closure risk.'*

We apply screening thresholds to the full set of radiological capacities and activity concentration limits derived in our assessments to identify which radionuclides require a specific capacity or limit. Any radionuclides with a capacity or limit above the relevant threshold for a given assessment case are grouped as 'other' radionuclides<sup>20</sup>. Our approach to deriving screening thresholds for LLW is set out in Subsection 6.2.1. We consider how our approach might change if higher activity wastes were accepted in Subsection 6.2.2.

### 6.2.1 Screening Thresholds if Only LLW is Accepted

An appropriate basis for screening controls on LLW is provided by the upper limit placed on disposals by the 4 and 12 GBq t<sup>-1</sup> LLW limits as given in the Permit [23].

The current screening thresholds (for LLW) were derived on the following basis.

- When applying the sum-of-fractions methodology, individual radiological capacity values are used for all potentially significant radionuclides. For the specified radionuclides, the activity in the waste is divided by the radiological capacity to give a sum-of-fractions contribution. The radionuclides for which values are not individually specified are grouped as 'others' and a common value is set for the radiological capacity of these radionuclides. These 'other' radionuclides are those that have radiological capacities greater (i.e. are less restrictive) than the value assigned to the 'others' group. Radionuclides with half-lives less than 3 months are excluded from consideration.
- In principle, radionuclides identified as 'others' might be considered for exclusion from any control, other than that provided by the LLW limits. However, in order to provide reassurance that all radionuclides are controlled within the sum-of-fractions methodology, the screened radionuclides are included within the assessment using the term 'others'. Their contributions to the sum of fractions will still be recorded and, by this method, will be over-estimated but not so as to significantly overestimate the total sum-of-fractions value.
- Radionuclides not allocated specific radiological capacity limits are those that, even if all of the wastes disposed of to the vaults comprise such radionuclides at the level of the LLW limit, the dose or risk associated with those radionuclides would not exceed 5% of the relevant regulatory criterion (i.e. 0.05 of the sum of fractions).
- Rather than set separate screening thresholds for alpha and beta activities, screening thresholds of 300 GBq t<sup>-1</sup> and 1,000,000 TBq have been derived for consignment activity and total vaults activity respectively<sup>21</sup>. These values represent

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<sup>20</sup> Radionuclides that were not included in our assessments, as they were not identified as potentially important for the ESC by our Radiological Hazard Index model, are also grouped as 'other' radionuclides.

<sup>21</sup> The maximum activity of unspecified nuclides cannot exceed the LLW limits of 4 and 12 GBq t<sup>-1</sup> for alpha and non-alpha emitting radionuclides respectively, 16 GBq t<sup>-1</sup> in total. For this level of activity to contribute at most a value of 0.05 to the sum of fractions, the assigned radiological capacity when considering consignment limits must be approximately 300 GBq t<sup>-1</sup> (16 GBq t<sup>-1</sup> divided by 300 GBq t<sup>-1</sup> equals ~ 0.05). Assuming a maximum quantity of waste in the vaults of about 3 million tonnes, the 300 GBq t<sup>-1</sup> consignment based radiological capacity

approximately 20 times the maximum quantities that can be consigned to the site because of the control provided by the 4 and 12 GBq t<sup>-1</sup> LLW limits.

Screening on this basis ensures that radionuclides not individually limited will have a combined impact of less than 5% of the regulatory criteria. This simplifies the screening approach and also ensures screening is set at an appropriately low level to capture all radionuclides of importance. Moreover, the contribution of the screened radionuclides will be very much less than 0.05 to the sum of fractions. This is because their activities are often significantly less than the 4 and 12 GBq t<sup>-1</sup> LLW limits and because their true radiological capacity or activity concentration limits will be significantly greater than the screening values. In addition, it can be shown that the number of radionuclides identified by screening is relatively insensitive to the precise screening values adopted.

For each pathway and assessment case discussed in Subsection 6.1 therefore, the screening thresholds noted above are applied. The use of this approach for 'other' radionuclides is included in the illustration of the sum-of-fractions approach in Box 6.1.

### **6.2.2 Screening Criteria if Higher Activity Wastes Were Accepted**

To move to a fully risk-based approach to the disposal of waste at the LLWR, the application of the LLW limits of 4 and 12 GBq t<sup>-1</sup> would need to be replaced by new controls derived from the LLWR's safety cases and regulatory limits and guidance levels. These controls would be specific to the disposal of waste at the LLWR.

If a decision were taken to accept wastes with activity higher than the 4 and 12 GBq t<sup>-1</sup> LLW limits, retention of the screening thresholds based on the LLW limits may be overly cautious. This is because some radionuclides are more radiotoxic than others. If the LLW screening thresholds were retained, it could result in more radionuclides being grouped into 'others' than is appropriate.

As discussed in the introduction to Subsection 6.2 and reference [15], we consider a subset of radionuclides in our assessments based on our Radiological Hazard Index model. Radiological capacities and activity concentration limits are only derived for the radionuclides we consider in our assessments.

The Radiological Hazard Index model used the Stage 1 Reference Inventory, which included a subset of the ILW that might be suitable for disposal at the LLWR. As decommissioning progresses, waste producers will characterise their wastes and activities may be different to those specified in the current UKRWI. Therefore, even if we choose not to apply a screening threshold to reduce the number of radionuclides for which a capacity or limit is specified, we still require a capacity or limit for radionuclides that have not been assessed. The exception to this is radionuclides with a short half-life that would decay before impacts could occur.

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value equates to approximately 1,000,000 TBq (16 GBq t<sup>-1</sup> × 0.001 TBq GBq<sup>-1</sup> × 3,000,000 t divided by 1,000,000 TBq equals ~ 0.05). Note the mass of packaged waste in the Stage 3 inventory (including ILW) is 1.2 million tonnes.

We have assessed whether retention of the current screening approach makes a significant difference to the sum-of-fractions results for different assessment cases, if ILW was accepted in addition to LLW. The analysis is specific to each assessment and is discussed in the relevant subsections of 6.3 and 6.4. Where appropriate, the analysis considered all ILW in the UKRWI to ensure that the conclusions would be appropriate independent of the reference inventory, as the reference inventory provides an indication of how capacity might be used for ILW rather than a forecast.

## **6.3 Controls on Total Inventory**

### **6.3.1 Groundwater**

In the groundwater assessment, radiological capacities for the post-PoA period have been calculated based on the risk guidance level of  $10^{-6}$  per year [20]. Radiological capacity values have been calculated based on the probabilistic reference case. In this case, some input parameters are represented by probability density functions, which are sampled in each run of the model. The model is run multiple times and the mean risk (i.e. expectation value) to the receptor for each pathway is calculated assuming disposal of a unit inventory to the vaults [64]. For each pathway, the mean risk for each radionuclide, taking into account contributions from ingrown daughters, is used to calculate separate capacities.

As explained in Subsection 6.1.2, when calculating the sum of fractions for groundwater cases, allowance must be made for the combined impacts from both vaults and trenches. The calculated peak mean risk from the trenches was subtracted from the risk guidance level to calculate a 'risk budget' for the vaults. The risk budget for the vaults was used to derive capacities for the vaults. The derived capacities therefore apply to both wastes already disposed to the vaults and future wastes, and therefore sum-of-fractions calculations should take into account the disposed waste activity in the vaults.

As discussed in Subsection 6.1.2, the well and marine pathways are considered in our derivation of capacities. When the LLW screening threshold of  $1 \times 10^6$  TBq is applied, all radionuclides assessed are most limited either by the well pathway or have a capacity above the screening threshold, apart from Ag-108m, Cm-248, Ho-166m and Nb-94, which are most limited by the marine pathway.

We have used the Stage 3 Reference Inventory [4] to consider whether to combine the capacities from the well and marine pathway into a single set of capacities or apply them individually. The total sum of fractions from the Stage 3 Reference Inventory (when the LLW screening criterion of  $1 \times 10^6$  is applied) is 0.026 for the well pathway, 0.019 for the marine pathway and 0.027 if the most restrictive capacity is applied for each radionuclide. As combining the constraints into a single set of capacities by taking the most restrictive capacity for each radionuclide does not significantly increase the sum of fractions, we propose to use the combined constraints.

The proposed radiological capacities for the groundwater pathway are given in Table 6.3. Radionuclides with capacities that are higher than the screening level are not listed and are

included within the 'others'. For this pathway, this includes tritium, with a relatively high radiological capacity value of  $1.2 \times 10^{10}$  TBq (for the well pathway) due to its relatively short half-life of 12.3 years. The 'others' also includes radionuclides such as Cs-137 and plutonium isotopes with high-capacity values principally due to their retardation in the near field and geosphere.

**Table 6.3: Radiological capacity values for groundwater**

Radionuclide	Radiological Capacity Values <sup>22</sup>
	TBq
Ag-108m	160
Ca-41	14,000
Cl-36	1,700
Cm-248	500,000
Cs-135	610
Ho-166m	24,000
I-129	11
Mo-93	13,000
Nb-94	66,000
Ni-59	250,000
Np-237	9,200
Pa-231	150
Ra-226	280
Tc-99	14,000
Th-229	180
Th-230	230

<sup>22</sup> Here, and in subsequent tables, radiological capacity values are given to two significant figures in recognition of the accuracy of the underlying assumptions rather than the more precise values cited elsewhere in the ESC.

Radionuclide	Radiological Capacity Values <sup>22</sup>
	TBq
Th-232	48
U-233	1,000
U-234	24,000
U-235	4,300
U-236	130,000
U-238	110,000
Zr-93	17,000
Others*	1 10 <sup>6</sup>

\*Radionuclides of less than 3 months half-life are not limited.

We have considered whether retaining the screening threshold of 1 10<sup>6</sup> TBq would be unduly constraining if a decision was taken to accept ILW in addition to LLW.

If the screening threshold of 1 10<sup>6</sup> TBq is not applied to radionuclides assessed in the groundwater assessment, the marine pathway has the most restrictive capacity for 26 radionuclides and the well pathway has the most restrictive capacity for the remaining radionuclides assessed.

Combining the capacities into a single set using the most restrictive capacity for each radionuclide does not significantly increase the total sum of fractions for vault wastes compared to applying each set of constraints separately.

Using the most restrictive capacity for each radionuclide assessed and using a capacity of 1 10<sup>6</sup> TBq for any radionuclide not assessed in the groundwater assessment (excluding any with a half-life of less than 3 months), the sum-of-fractions value for the Stage 3 Reference Inventory for the vaults is 0.01. Although this is less than the sum of fractions when a screening threshold of 1 10<sup>6</sup> TBq is applied to group some of the assessed radionuclides into 'others' (0.027), the total sum of fractions is very low in both cases. Application of the screening threshold is therefore unlikely to have an impact on what waste might be accepted. We therefore conclude that retention of the LLW screening threshold of 1 10<sup>6</sup> TBq would not be unduly constraining if a decision was taken to accept ILW in addition to LLW.

### 6.3.2 Gaseous Releases

Radon is dominantly generated through decay of disposed Ra-226. The amount of Ra-226 that in-grows from disposed isotopes of thorium and uranium is relatively small over the assessment timescales [111]. We therefore only derive a capacity for Ra-226 for the radon

gas pathway. The most restrictive capacity derived for Ra-226 is for the case when the geomembrane is intact and the cap vent is closed. The derived remaining capacity for Ra-226 after existing disposals have been taken into account is 1.3 TBq [111].

Releases of C-14, and hence calculated risks from the C-14-bearing gas pathway, are dependent on the waste material with which the C-14 is associated and the container in which the waste is assumed to be disposed. Risks and capacities were calculated for three different container types (the current HHISO, a strengthened HHISO and a strengthened ILW container) and for different material types. We do not yet have detailed designs for a strengthened HHISO or a mild steel strengthened ILW container. It may be difficult for waste producers to identify the material association of C-14 and we would need to discuss the practicality of implementing material-specific capacities with them. For these reasons, we have derived a single capacity for the current HHISO container for use until we implement the strengthened HHISO. The capacity applies to C-14 regardless of the material association, and accounts for the split of C-14 between different materials in LLW assumed to be disposed in the current HHISO design in the Stage 2 Reference Inventory. The lowest capacity of those selected for consideration is from the vent closed early geomembrane failure case, and is 15 TBq [111].

As discussed in Subsection 6.1.1, in some exposure cases a receptor could be affected by both radon and C-14. We have cautiously taken the risk from a unit inventory prior to geomembrane failure for radon and the risk from a unit inventory after geomembrane failure for C-14 when deriving remaining capacity for each radionuclide.

In order to ensure the combined risk from radon and C-14 bearing gases does not exceed the risk guidance level of  $10^{-6}$  per year we have allocated a proportion of the sum of fraction to each pathway. The total activity of Ra-226 in future wastes (across all container types) in the Stage 2 Reference Inventory would use 2.1% of the Ra-226 capacity. We have therefore allocated 3% of the gas capacity to Ra-226 and 97% of the gas capacity to C-14. The corresponding capacities, which are to be applied to future disposals only, are shown in Table 6.4. These capacities apply to each radionuclide separately rather than using a sum-of-fractions approach. It is not necessary to use a sum-of-fractions approach when using these capacities as we have already allocated 3% of the gas capacity to Ra-226 and 97% of the gas capacity to C-14 in deriving the values in Table 6.4.

**Table 6.4: Radiological capacity values for the gas assessment**

Radionuclide	Capacity for future wastes (TBq)
C-14	14.5
Ra-226	0.04

There would be sufficient capacity to accept all of the radon in the Stage 2 Reference Inventory within the capacities set out in Table 6.4. There would also be sufficient capacity to accept all of the C-14 in LLW allocated to Vault 9 and 9A in the Stage 2 Reference Inventory.

However, there would not be sufficient C-14 capacity to accept all of the C-14 in LLW allocated to Vault 10 onwards. We expect the strengthened container to be implemented well before this.

We propose to operate to the capacities set out in Table 6.4 until the strengthened HHISO is in use. Once we implement the strengthened container, we would recalculate the remaining capacity for C-14 based on its use. We would also review the remaining Ra-226 capacity and our allocation of the proportion of the gas sum of fraction assigned to the radon and C-14 bearing gas pathways. Based on our gas assessment calculations, the revised C-14 capacity for the new containers would be higher than the value in Table 6.4. The scale of the increase will depend on when the strengthened container is implemented, the distribution of C-14 between different materials and whether we decided to set material-specific capacities. Material specific capacities for C-14 in the strengthened HHISO range from 360 TBq to  $1.5 \times 10^5$  TBq [111].

We would consider bespoke assessments (see Subsection 8.3) for individual waste streams with high C-14 activity where the material association is known. Arrangements set out in Subsection 8.1.2 would ensure these waste streams were identified in advance.

Potential radon doses are sensitive to bulk gas generation rates. If there was a significant change to understanding of potential bulk gas generation rates in future, for example because the forecast material inventory changed significantly, we would review radon capacities (and container limits, see Subsection 6.4.1.3).

If the amount of radon in the forecast LLW inventory from the UKRWI were to significantly increase in future, we would consider whether it was appropriate to change the proportion of the gas assessment sum of fraction allocated to Ra-226 and C-14.

If a decision were taken to accept ILW for disposal and the ILW was disposed in a different container to the strengthened HHISO, it may be necessary to derive C-14 capacities for the ILW container. Of the 0.029 TBq Ra-226 in the Stage 2 forward inventory, 0.028 TBq is associated with LLW. If ILW was proposed for disposal that had higher Ra-226 content than was included in the Stage 2 reference inventory, we would need to review whether to change the relative allocation of the gas assessment capacity to Ra-226 and C-14. This review would need to take into account what was considered best use of the LLWR's capacity, as discussed in Subsection 8.1.2.1.

### **6.3.3 Coastal Erosion**

In the coastal erosion assessment, radiological capacities have been calculated based on the  $10^{-6}$  GRA risk guidance level, assuming exposure occurs, which is equivalent to an annual dose criterion of 20  $\mu$ Sv per year [20]. Results have been reported [112] for exposure groups who may be exposed to radioactivity in eroded waste as a result of:

- recreational use of the coastline adjacent to the LLWR;
- consumption of local marine foodstuffs; and

- occupational use of the St Bees to Ravenglass coastline.

Capacities are calculated based on the reference case, which assumes erosion commences in 1,250 years and continues for a further 2,000 years. Analysis of the results for these three cases shows that all three cases lead to the most restrictive capacities for different radionuclides [112]. The radiological capacity values for all three cases are given in Table 6.5. For each radionuclide the most restrictive value is shown in bold. Radionuclides with capacities less restrictive than the LLW screening threshold are not listed and are included within the 'others'. This category includes, for example, Sr-90, Cs-137, Pb-210 and Cm-242.

**Table 6.5: Radiological capacity values for coastal erosion cases**

Radionuclide	Recreational receptor TBq	High-rate Marine Foodstuff Consumer TBq	Occupational receptor TBq
Ag-108m	<b>68</b>	940	89
Am-241	2,800	<b>2,600</b>	<b>2,600</b>
Am-242m	<b>50,000</b>	73,000	91,000
Am-243	74	150	<b>38</b>
C-14	14,000	<b>520</b>	1 10 <sup>6</sup>
Cl-36	<b>850</b>	1 10 <sup>6</sup>	1 10 <sup>6</sup>
Cm-243	300,000	<b>85,000</b>	110,000
Cm-244	150,000	<b>43,000</b>	58,000
Cm-245	110	79	<b>48</b>
Cm-246	450	<b>180</b>	190
Cm-248	7.4	36	<b>3.8</b>
Cs-135	4,200	110,000	<b>2,300</b>
Ho-166m	<b>17</b>	4,300	22
I-129	2,400	2,000	<b>1,300</b>
Mo-93	110,000	<b>98,000</b>	1 10 <sup>6</sup>

Radionuclide	Recreational receptor TBq	High-rate Marine Foodstuff Consumer TBq	Occupational receptor TBq
Nb-94	7.9	12,000	<b>4.6</b>
Ni-59	730,000	<b>340,000</b>	390,000
Np-237	57	600	<b>56</b>
Pa-231	17	28	<b>15</b>
Pu-238	1 10 <sup>6</sup>	<b>760,000</b>	1 10 <sup>6</sup>
Pu-239	360	<b>100</b>	140
Pu-240	410	<b>120</b>	160
Pu-241	81,000	76,000	<b>74,000</b>
Pu-242	350	<b>100</b>	140
Pu-244	27	83	<b>14</b>
Ra-226	11	<b>4.1</b>	10
Tc-99	<b>3,600</b>	7,800	1 10 <sup>6</sup>
Th-229	37	<b>20</b>	<b>20</b>
Th-230	10	<b>2.8</b>	6.8
Th-232	4.5	21	<b>2.5</b>
U-233	170	91	<b>89</b>
U-234	740	<b>240</b>	430
U-235	73	600	<b>43</b>
U-236	4,000	26,000	<b>1,700</b>
U-238	140	21,000	<b>77</b>
Zr-93	56,000	<b>16,000</b>	30,000

<b>Radionuclide</b>	<b>Recreational receptor TBq</b>	<b>High-rate Marine Foodstuff Consumer TBq</b>	<b>Occupational receptor TBq</b>
Others*	1 10 <sup>6</sup>	1 10 <sup>6</sup>	1 10 <sup>6</sup>

\*Others exclude radionuclides of less than 3 months half-life.

As discussed in Subsection 6.1.4, for the coastal erosion cases impacts from the vaults and trenches are independent from each other. We therefore derive capacities for waste disposed in the vaults. The capacities will apply to both wastes already disposed to the vaults and future wastes, therefore sum-of-fractions calculations should take into account the disposed waste activity in the vaults.

There are two possible approaches for defining vault capacities based on the coastal erosion assessment.

- 1) Define independent sets of capacities for each assessment case, as set out in Table 6.5. To apply these capacities, three independent sums of fraction calculations would be required.
- 2) Define a single set of capacities with the limit for each radionuclide set to the most restrictive value from the three assessment cases.

The second approach is more cautious, as the derived values do not all relate to the same exposed group. We have investigated whether the capacities from these cases should be combined by calculating the following sums of fractions for the disposed and forward LLW inventory for the vaults.

- Sum of fractions for each case individually, with the capacity for any radionuclides with a derived capacity above the LLW screening threshold set to 1 10<sup>6</sup> TBq.
- Sum of fractions using a single set of constraints, applying the most restrictive capacity for each radionuclide and with the capacity for any radionuclides with derived capacities above the LLW screening threshold for all three cases set to 1 10<sup>6</sup> TBq.

Radionuclides that were not assessed in the coastal erosion assessment were allocated a capacity of 1 10<sup>6</sup> TBq. Radionuclides that are unlimited based on the coastal erosion assessment or have a half-life of less than 3 months were excluded from the calculations.

The individual sums of fractions were 0.08, 0.15 and 0.15 for the recreational, high-rate marine foodstuff consumer and occupational receptors respectively. The sum of fractions increased to 0.22 when a single set of capacities, consisting of the most restrictive capacity from across the three cases for each radionuclide, was applied. This is an increase in the sum of fraction of around 47% compared to the high-rate marine foodstuff consumer and occupational receptors. On this basis, we do not combine the capacities into a single set.

The sum of fractions for the recreational receptor is lower than the other two pathways, and the recreational receptor leads to the most restrictive capacity for only five radionuclides (Ag-108m, Am-242m, Cl-36, Ho-166m and Tc-99). These radionuclides contribute no more than 0.002 each to the total sum of fractions for the recreational receptor for LLW. On this basis, impacts to this receptor would be constrained by capacities for the high-rate marine foodstuff consumer and occupational receptors. We will therefore apply the constraints for the high-rate marine foodstuff consumer and occupational receptors. These are presented in Table 6.6.

**Table 6.6 Proposed coastal erosion capacities**

<b>Radionuclide</b>	<b>High-rate Marine Foodstuff Consumer TBq</b>	<b>Occupational receptor TBq</b>
Ag-108m	940	89
Am-241	2,600	2,600
Am-242m	73,000	91,000
Am-243	150	38
C-14	520	1 10 <sup>6</sup>
Cm-243	85,000	110,000
Cm-244	43,000	58,000
Cm-245	79	48
Cm-246	180	190
Cm-248	36	3.8
Cs-135	110,000	2,300
Ho-166m	4,300	22
I-129	2,000	1,300
Mo-93	98,000	1 10 <sup>6</sup>
Nb-94	12,000	4.6
Ni-59	340,000	390,000

<b>Radionuclide</b>	<b>High-rate Marine Foodstuff Consumer TBq</b>	<b>Occupational receptor TBq</b>
Np-237	600	56
Pa-231	28	15
Pu-238	760,000	1 10 <sup>6</sup>
Pu-239	100	140
Pu-240	120	160
Pu-241	76,000	74,000
Pu-242	100	140
Pu-244	83	14
Ra-226	4.1	10
Tc-99	7,800	1 10 <sup>6</sup>
Th-229	20	20
Th-230	2.8	6.8
Th-232	21	2.5
U-233	91	89
U-234	240	430
U-235	600	43
U-236	26,000	1,700
U-238	21,000	77
Zr-93	16,000	30,000
Others*	1 10 <sup>6</sup>	1 10 <sup>6</sup>

\*Others exclude radionuclides of less than 3 months half-life.

The radiological impacts arising from coastal erosion are primarily determined by the level of radioactivity exposed at or released from the cliff face in a given period, rather than the total

inventory contained within the vaults themselves. However, assessment calculations for LLW indicate that there is no significant variability in impact across different vaults, and all predicted impacts remain comfortably within established guidance levels [107]. When combined with controls on items, sources, and particles (Subsection 6.5), the application of overall vault limits ensures adequate control of any heterogeneity in potential impacts, though trends will continue to be monitored (Subsection 3.4).

### 6.3.3.1 Additional Controls for ILW

#### Screening levels

We have considered if the capacity approach would need to change if ILW were to be accepted for disposal in addition to LLW. Sums of fractions were calculated for the Stage 3 reference inventory, and for the LLW reference inventory combined with all ILW streams in the UKRWI, excluding ILW streams that:

- would never be sent to the LLWR regardless of their activity, for example because they are covered by Scottish Higher Activity Waste Policy;
- have a sum-of-fractions value greater than one when assessed on their own, as these are unlikely to ever be acceptable at the LLWR.

For the Stage 3 reference inventory, if the capacities derived in the coastal erosion assessment are applied for all radionuclides assessed (i.e. no threshold is applied) and the capacity for all other radionuclides with a half-life longer than 3 months is set to  $1 \times 10^6$  TBq, the sum of fractions for the occupational receptor and high-rate marine foodstuff consumer were 0.43 and 0.64 respectively. If a screening threshold of  $1 \times 10^6$  TBq is applied (i.e. the capacity is set to  $1 \times 10^6$  TBq for any radionuclides with a derived capacity higher than this), the occupational user sum of fractions is still 0.43 and the high-rate marine foodstuff consumer sum of fractions is 0.65.

When all ILW of interest (excluding streams unlikely to be sent to LLWR as discussed above) is considered alongside LLW, application of a screening threshold of  $1 \times 10^6$  TBq increases the sum of fractions for the occupational receptor to 21.7, compared to 22.38 if all capacities derived in the coastal erosion assessment are used. The sum of fractions for the high-rate marine foodstuff consumer increases from 24.7 to 25.3.<sup>23</sup>

If the capacity used for radionuclides not assessed in the coastal erosion assessment is increased from  $1 \times 10^6$  TBq to  $1 \times 10^7$  TBq or  $1 \times 10^8$  TBq, the total sums of fractions do not change for the Stage 3 reference inventory. This demonstrates that radionuclides that were not assessed within the coastal erosion assessment are not making a significant contribution to the total sum of fractions. When all ILW of interest is considered, the total sums of fractions reduce to 20.5 and 20.3 for the recreational receptor using capacities of  $1 \times 10^7$  TBq or  $1 \times 10^8$  TBq respectively for radionuclides not assessed in the coastal erosion assessment. For the high-rate marine foodstuff consumer, the sums of fractions reduce to 22.5 and 22.3

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<sup>23</sup> These calculations are only used to explore the implications of different screening levels. In reality, only a small subset of the ILW would ever be disposed.

respectively. The sums of fractions are very similar in each case when  $1 \times 10^7$  TBq or  $1 \times 10^8$  TBq are applied as screening thresholds to radionuclides included in the coastal erosion assessment, in addition to being used for radionuclides not included in the assessment.

Our analysis demonstrates that application of the  $1 \times 10^6$  TBq LLW screening threshold does not make a significant difference to the calculated sums of fractions. We would therefore retain the constraints in Table 6.6 if a decision is taken to accept ILW in addition to LLW.

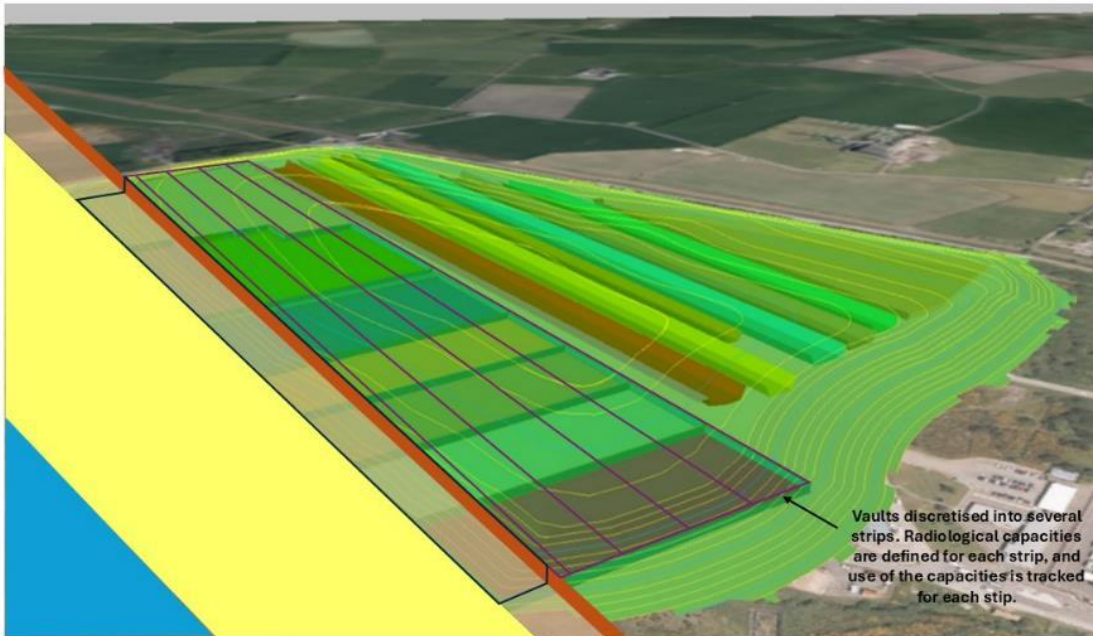
### **Heterogeneity of activity**

The spatial distribution of ILW inventories within repository vaults is less uniform than for LLW, leading to potential variations in radiological hazard. The inclusion of ILW, particularly in shielded modules, increases the significance of sub-vault scale heterogeneity compared with LLW-only disposal, requiring controls to ensure impacts do not exceed the risk guidance level.

To manage this, the repository would be divided into several coast-parallel strips, each monitored and managed for its radiological capacity (Figure 6.1). Radiological capacities are calculated assuming a homogeneous distribution of radionuclides, then apportioned between strips based on their length in the erosion direction. Tracking of capacity usage (Subsection 3.4) would focus on key radionuclides and be updated periodically. In addition, waste streams that would represent an elevated proportion of total vault capacity would be assessed in advance (Subsection 8.1.2). Five strips, each under 40 metres wide, are suggested as a practical balance between operational feasibility and the length scales of interest. This approach is especially important if ILW is disposed in distinct vault areas and is primarily aimed at protecting recreational coastal users, with additional controls sufficient to safeguard occupational users and marine foodstuff consumers. The 40 metres is a reasonable scale, based on the following considerations.

- Assessment model results show the distance the cliff line needs to erode for radionuclide concentrations on the storm beach to approach equilibrium with the waste being eroded from the cliffs is around 10 m to 15 m. Heterogeneity at smaller length scales is likely to be less significant for potential doses, as peaks in cliff radionuclide concentrations would not result in peaks in beach radionuclide concentrations at the same time.
- We expect erosion to proceed in a 'swash-aligned' orientation. This means that the erosion front will remain oriented parallel to the vault walls (following the purple lines in Figure 6.1) during erosion. One degree of misalignment between the erosion front and the long axis of the vaults results in 11.5 m difference in the amount of erosion of the north end of the vaults compared with the southern end (assuming the last vault is Vault 12). It is reasonable to expect there could be 20 m to 30 m misalignment of the erosion front compared with the perfect alignment assumed in the capacity calculations.

- There may be small-scale variations in the geomorphology of the cliffs that cannot be projected. For example, reflecting areas where local conditions have resulted in enhanced waste and container degradation, and faster erosion of the wastes, or where there has been greater slumping of the exposed waste. These features could also have length scales of the order 10 m to 20 m in the direction of erosion.



**Figure 6.1: Discretisation of the vaults into coast parallel strips to manage sub-vault scale spatial heterogeneity in the inventory and radiological hazard [107]**

### 6.3.4 Overall Limits on Vaults

In this section, all the radiological capacity values that are relevant to the setting of limits on the total inventory of the site are considered in order to establish a suitable overall basis for controls. The relevant radiological capacity values are:

- Groundwater, with values presented in Table 6.3, applied to all wastes in the vaults, including wastes already disposed in the vaults.
- Gaseous release (in the long term), with values as presented in Table 6.4.
- Coastal erosion, with values presented in Table 6.6, applied to all wastes in the vaults, including wastes already disposed in the vaults.

The gas pathway is more limiting for C-14 and Ra-226 than either the coastal erosion or groundwater pathways. For other radionuclides, generally, the coastal pathway is more limiting than the groundwater pathway, with the exception of Ca-41, Cl-36, Cs-135, I-129, Mo-93 and Ni-59. To provide controls in accordance with regulatory criteria, we have developed four separate sets of radiological capacities:

- limits relating to the groundwater pathway, as set out in Table 6.3;
- limits relating to the gas pathway, as set out in Table 6.4;
- limits relating to the High-rate Marine Foodstuff Consumer for the coastal erosion pathway, as set out in Table 6.5;
- limits relating to the Occupational Receptor for the coastal erosion pathway, as set out in Table 6.6.

There are 37 radionuclides for which we have derived a radiological capacity below the LLW screening threshold of  $1 \times 10^6$  TBq in our 2026 ESC assessments. Of these 37 radionuclides:

- The most restrictive radiological capacity for 11 radionuclides is higher than the most restrictive capacity in the current Permit. The increase is generally a factor of less than ten, with the exceptions of Cl-36 and Mo-93, which have increased by factors of 50 and 100 respectively.
- The most restrictive radiological capacity for 26 radionuclides is lower than the most restrictive capacity in the current Permit. The decrease is generally a factor of less than five, with the exceptions of C-14, Cs-135, Ho-166m, Pu-244 and Ra-226 which are lower by factors of 9, 210, 45,000, 71,000 and 95 respectively.

Ho-166m, Ni-59 and Pu-244 are included within the 'other' category for all pathways in the current Permit. All three radionuclides have capacities below  $1 \times 10^6$  TBq from the 2026 ESC coastal erosion assessment and Ho-166m and Ni-59 also have capacities below  $1 \times 10^6$  TBq from the 2026 ESC groundwater assessment, so would no longer be categorised as 'others'.

Tritium and Se-79 have capacities in the current Permit, but would be categorised as 'other' based on the 2026 assessments. The current tritium capacity is based on doses from aerial release of tritium during the PoA. We have concluded we do not need to apply a capacity for tritium for this pathway based on our 2026 PoA assessment. Se-79 was not assessed in the 2026 ESC as our Radiological Hazard Index model indicated that it was not an important contributor to dose [15].

The current Permit does not include a capacity for Ra-226 based on the radon gas pathway. The capacity derived in the 2026 ESC based on the radon gas pathway (0.04 TBq) is a factor of ten lower than the most restrictive capacity for Ra-226 in the current Permit (3.8 TBq for the high-rate marine foodstuff consumer coastal erosion case).

We have compared the capacity that would be used by the Stage 3 LLW inventory based on our current Permit and the capacities derived in the 2026 ESC, as shown in Table 6.7. The beach user coastal erosion case in the Permit is compared to the occupational receptor for the 2026 ESC as the occupational receptor was found to be more restrictive than the 2026 ESC equivalent of the beach user receptor.

**Table 6.7: Comparison of capacity usage by the Stage 3 LLW inventory for the current Permit and the 2026 ESC capacities**

Assessment case	Sum of fractions using the current Permit capacities	Sum of fractions using the 2026 ESC capacities
Groundwater	0.18	0.01
Coastal erosion, high-rate marine foodstuff consumer	0.16	0.15
Coastal erosion, beach user (current Permit) or occupational receptor (2026 capacities)	0.11	0.15

The sum-of-fractions value for groundwater is more than an order of magnitude lower using the 2026 ESC capacities. This is because the key radionuclides for the groundwater pathway have changed compared to the assessment that underpinned the current Permit. Previously the key radionuclides were I-129, Cl-36 and C-14 and the 2026 ESC capacities for all three radionuclides are higher than the capacities in current Permit. Th-232, Ra-228 and Th-228 are the key radionuclides for the probabilistic case that was used to derive the 2026 ESC groundwater capacities. The 2026 ESC capacities for Ra-228 and Th-228 are high as releases from the vaults are low for these radionuclides - the impacts arise due to releases from the trenches prior to installation of the final cap.

The sums of fractions for the coastal erosion cases are very similar for both sets of capacities.

The C-14-bearing gas capacity has decreased compared to the current Permit. However, we expect the capacity to increase when the strengthened container is implemented, as discussed in Subsection 6.3.2.

We have concluded that for LLW there is no requirement to subdivide the controls for the vaults to set limits for individual vaults arising from the assessment calculations. This is because either the contamination is mixed before exposure to a receptor occurs (as is generally the case for the groundwater and gas pathways) or the behaviour of the representative person means they are exposed to waste from multiple vaults (as is the case for coastal erosion). We have, however, put arrangements in place to monitor the rate of usage of both the radiological and volumetric capacities of the site and to discuss the findings with stakeholders. This is discussed further in Section 8.

We have also considered if there should be a volume constraint on disposals. However, the assessment results are not significantly dependent on this in terms of the limits determined in either this section for total activity or in Subsection 6.4 for consignments. Furthermore, disposals are to vaults that are subject to planning controls and approval. The latter involves

consultation with stakeholders, including the Environment Agency as a statutory consultee. We therefore consider that the rate of disposals and the total disposals to the site are sufficiently regulated that no additional constraint is required in terms of a volume limitation.

The application of these controls is discussed in Section 8.

## 6.4 Controls on Consignments

In addition to limits on the total quantities of radioactivity disposed of at the site, we also consider the potential requirement for limits on the quantities of radioactivity on a smaller scale. This section presents the derivation of limits for disposed wastes on a waste consignment scale.

The Permit includes activity concentration limits of 4 GBq t<sup>-1</sup> for alpha emitting radionuclides and 12 GBq t<sup>-1</sup> for all other radionuclides [23]. These limits come from the definition of LLW. The limits are applied to each consignment disposed of, which can be of up to 40 m<sup>3</sup> in volume [23]. There are no other restrictions within the Permit in terms of activity concentration limits. This was consistent with UK Government policy [115] at the time of the 2011 ESC submission. A new policy for managing radioactive substances and nuclear decommissioning was adopted in May 2024 [26] which states that operators should adopt a 'risk-informed' approach to disposal. New controls would be required to replace the application of the LLW limits, if a decision was taken to accept ILW at the LLWR. However, we are not seeking to change the activity concentration limits at this time. This subsection therefore focuses on using activity concentration limits to inform emplacement controls for LLW. We also discuss potential approaches for replacing the 4 GBq t<sup>-1</sup> and 12 GBq t<sup>-1</sup> limits, if a decision was taken to accept ILW at the LLWR.

In addition to controls on activity concentration to inform emplacement, we also consider whether limits on activity in a consignment are required. As discussed in Subsection 6.1.1, heterogeneity in the spatial distribution of the inventory leads to heterogeneity in potential doses to people living on the cap, particularly for radon. With the vent closed and cap geomembrane intact, most of the radon flux to a house located over a defect (small hole) in the geomembrane comes from the container immediately below the defect and the immediately adjacent containers. To limit the maximum radon doses to individual houses above such defects, we have considered potential limits on activity of Ra-226 in a single container.

As discussed in Subsection 6.1, some of the scenarios and assessment cases presented elsewhere in the ESC show that impacts in some exposure situations are determined by specific activities averaged over some volume as opposed to the total quantities disposed. Relevant assessment cases include external doses during the PoA and potential human intrusion into and direct contact with wastes including discrete items, sources and active particles [108].

Doses from external irradiation during the PoA need to be considered. For the reasons discussed below, these are expected to be dominated by consignments placed at the edges of the vaults, above the height of the vault walls.

The human intrusion assessment events consider impacts to:

- Members of groups who might intrude into the wastes during site investigation or building work, represented as borehole driller, trial pit excavator, laboratory analyst and construction workers.
- Members of groups who might spend significant amounts of time on the cap area subsequent to intrusions, represented as house occupier and smallholders.
- Members of groups who might be exposed to wastes during the period when wastes are present on the beach or cliff face during coastal erosion, represented as informal and local organised scavengers (this is not considered to be human intrusion, but the cases are addressed as part of the human intrusion assessment as the same dose criteria apply).

Further descriptions and details of these events are given in the relevant assessment report [98]. In using the results of the assessment calculations for the setting of potential activity concentration limits, it is important to consider how exposures to the wastes may occur. This is because a distinction can be made between those human activities that might lead to exposure to wastes at any depth within the facility and those activities which can only lead to exposure to wastes at the upper stack levels.

During site investigation, the borehole driller could be exposed to wastes at any depth, as could the laboratory analyst working on retrieved borehole drilling materials. The same also applies for those events associated with coastal erosion, namely the informal scavenger and local organised scavenger. In contrast, trial pits during site investigation work and excavations for construction are typically limited to a depth of about 6 m. Given the thickness of the cap overlying the wastes, this means excavation of any waste material is limited to the upper stack positions. Doses to other individuals who might live or have a smallholding on the contaminated ground after such an excavation could similarly only be exposed to waste extracted from upper stack positions.

Human intrusion cannot occur until after the end of the PoA, as controls will be in place to prevent any form of human intrusion during the PoA. Based on the UKRWI forecast and an institutional control period of 100 years, human intrusion could not occur until the year 2242 at the earliest. The informal scavenger and organised material recovery events could not occur until the repository begins to be eroded. These events cannot occur after the repository has been completely eroded. We have considered coastal erosion time frames for different climate emissions scenarios [72], and estimate that coastal erosion could begin around 750 years after present at the earliest, with the repository being completely eroded by 3,750 years after present at the latest.

In our assessment of inadvertent human intrusion [108], we calculate doses at defined times after disposal of a unit inventory. We have used doses calculated between 100 and 5,000 years after disposal of a unit inventory to identify capacities for events that could occur before or during coastal erosion. Doses calculated between 300 and 5,000 years after disposal of a unit inventory have been used to identify capacities for events that are only possible after the onset of coastal erosion. These date ranges have been selected to ensure that:

- disposals made towards the end of the PoA are appropriately limited;
- disposals of long-lived radionuclides or those with long-lived radionuclides in their decay chain are appropriately limited even if erosion of the repository takes longer than our estimates suggest.

This approach is cautious for radionuclides with half-lives such that disposals made in the near term would have decayed significantly before the end of the PoA (e.g. Cs-137 with a half-life of just over thirty years).

In deriving limits for cases that can only occur during or after coastal erosion, we assume that the earliest point for deriving limits is 300 years after disposal. Calculating capacities for 300 years after disposal, in addition to later, more realistic times, is very cautious. We consider 300 years to be a reasonable absolute minimum because institutional control measures could be extended to 300 years duration if climate change or coastal projections were to dramatically change in future compared to our current understanding. This approach is consistent with our approach to deriving limits for Discrete Items.

For each event we have selected the lowest limit calculated across the time frame of relevance for the case, either 300 to 5,000 years for events that can only occur during or after coastal erosion or 100 to 5,000 years for other events. This is cautious, as the time at which the highest dose (and hence lowest limit) is calculated varies between radionuclides, so a receptor would never receive the highest dose from all radionuclides at the same time.

The following subsections consider the derivation of controls applicable to all consignments and then the additional restrictions for upper-level consignments. Controls on the disposal at the sub-container scale are considered separately in Subsection 6.5 and controls on fissile radionuclides are considered in Subsection 6.6.

## **6.4.1 Controls Applicable to all Consignments**

### **6.4.1.1 Human Intrusion**

As described above, assessment calculations for potential impacts to the borehole driller, lab analyst, informal scavenger and organised material recovery events consider the potential for exposure to all layers of waste and therefore are considered as a potential basis for setting limits on all consignments. The informal scavenger and organised material recovery events are not considered to be human intrusion, but the events are addressed as part of the human intrusion assessment as the same dose criteria apply.

Examination of the calculated activity concentration limits results shows that for the majority of radionuclides, assessments of potential impacts to the informal scavenger receptor lead to the most limiting activity concentrations. The borehole driller is the most restrictive for twelve radionuclides and the laboratory analyst is most restrictive for two radionuclides. The derived limits are presented in Table 6.8, with the most restrictive limit for each radionuclide in bold.

**Table 6.8: Human intrusion assessment limits**

<b>Radionuclide</b>	<b>*Borehole driller limit GBq t<sup>-1</sup></b>	<b>*Laboratory worker limit GBq t<sup>-1</sup></b>	<b>**Informal scavenger limit GBq t<sup>-1</sup></b>
Ac-227	<b>42</b>	170	3,000
Ag-108m	7.2	67	<b>0.35</b>
Am-241	12	48	<b>2.6</b>
Am-242m	11	42	<b>3</b>
Am-243	9.3	39	<b>0.98</b>
C-14	8,500	7.6 10 <sup>4</sup>	<b>330</b>
Ca-41	4.5 10 <sup>5</sup>	4.1 10 <sup>6</sup>	<b>5.8 10<sup>4</sup></b>
Cl-36	680	6,200	<b>24</b>
Cm-242	4,200	1.6 10 <sup>4</sup>	<b>3,200</b>
Cm-243	<b>130</b>	560	700
Cm-244	620	2,400	<b>530</b>
Cm-245	6	24	<b>0.83</b>
Cm-246	11	41	<b>1.7</b>
Cm-248	2.00	9.6	<b>0.15</b>
Co-60	<b>1.70 10<sup>6</sup></b>	1.5 10 <sup>7</sup>	1.3 10 <sup>16</sup>
Cs-134	<b>1.3 10<sup>15</sup></b>	1.2 10 <sup>16</sup>	4.8 10 <sup>16</sup>
Cs-135	3,200	3 10 <sup>4</sup>	<b>120</b>

Radionuclide	*Borehole driller limit GBq t <sup>-1</sup>	*Laboratory worker limit GBq t <sup>-1</sup>	**Informal scavenger limit GBq t <sup>-1</sup>
Cs-137	<b>170</b>	1,600	580
Eu-152	<b>1,300</b>	1.2 10 <sup>4</sup>	1.3 10 <sup>6</sup>
Eu-154	<b>2.3 10<sup>4</sup></b>	2.1 10 <sup>5</sup>	7.7 10 <sup>9</sup>
H-3	<b>4.1 10<sup>8</sup></b>	3.4 10 <sup>9</sup>	2.7 10 <sup>12</sup>
Ho-166m	6.4	60	<b>0.26</b>
I-129	650	6,300	<b>58</b>
Mo-93	2.1 10 <sup>4</sup>	1.7 10 <sup>5</sup>	<b>2,100</b>
Nb-93m	<b>1.2 10<sup>7</sup></b>	5.7 10 <sup>7</sup>	6 10 <sup>9</sup>
Nb-94	6	56	<b>0.22</b>
Ni-59	3.8 10 <sup>5</sup>	3 10 <sup>6</sup>	<b>1.9 10<sup>4</sup></b>
Ni-63	1.2 10 <sup>5</sup>	1 10 <sup>6</sup>	<b>1.9 10<sup>4</sup></b>
Np-237	14	63	<b>1.1</b>
Pa-231	1.1	4.5	<b>0.15</b>
Pb-210	<b>710</b>	4,900	4 10 <sup>4</sup>
Pu-238	21	82	<b>16</b>
Pu-239	9	35	<b>1.4</b>
Pu-240	9	35	<b>1.5</b>
Pu-241	360	1,400	<b>77</b>
Pu-242	9.3	36	<b>1.5</b>
Pu-244	5.2	23	<b>0.47</b>
Ra-226	4.4	36	<b>0.19</b>

Radionuclide	*Borehole driller limit GBq t <sup>-1</sup>	*Laboratory worker limit GBq t <sup>-1</sup>	**Informal scavenger limit GBq t <sup>-1</sup>
Ra-228	3.1 10 <sup>5</sup>	<b>3.6 10<sup>4</sup></b>	3.7 10 <sup>14</sup>
Ru-106	3.5 10 <sup>18</sup>	3.2 10 <sup>19</sup>	<b>1.2 10<sup>17</sup></b>
Sb-125	<b>1.40 10<sup>12</sup></b>	1.3 10 <sup>13</sup>	2.4 10 <sup>17</sup>
Sr-90	<b>1,200</b>	1.1 10 <sup>4</sup>	5,500
Tc-99	2,700	2.50 10 <sup>4</sup>	<b>100</b>
Th-228	1.1 10 <sup>16</sup>	<b>9.9 10<sup>14</sup></b>	7.8 10 <sup>16</sup>
Th-229	3.3	13	<b>0.39</b>
Th-230	3.3	20	<b>0.18</b>
Th-232	2.1	0.33	<b>0.11</b>
U-233	8.1	33	<b>0.97</b>
U-234	53	250	<b>4.2</b>
U-235	9.1	39	<b>0.9</b>
U-236	130	530	<b>21</b>
U-238	63	370	<b>3.40</b>
Zr-93	1.1 10 <sup>4</sup>	5.4 10 <sup>4</sup>	<b>1,000</b>

\*Borehole driller and Laboratory worker calculations use the higher end of the dose guidance level range (annual dose of 20 mSv) since they are limited in duration.

\*\*The Informal scavenger case uses the lower end of the dose guidance level range (annual dose of 3 mSv) since it occurs over a prolonged period.

When the LLW screening threshold of 300 GBq t<sup>-1</sup> is applied, the borehole driller case is most restrictive for three radionuclides (Ac-227, Cm-243 and Cs-137). For all other radionuclides, either the informal scavenger case limits or the screening threshold are more restrictive than the limits from other cases.

The derived activity concentration limits for Ac-227, Cm-243 and Cs-137 from the borehole driller case are 42, 130 and 170 GBq t<sup>-1</sup> respectively. The maximum amount of each radionuclide in a consignment is 12 GBq t<sup>-1</sup> for Ac-227 and Cs-137 and 4 GBq t<sup>-1</sup> for Cm-243, based on the definition of LLW. If we were to only apply the informal scavenger

limits, the limit for all three radionuclides would be set to the threshold of 300 GBq t<sup>-1</sup>, as the informal scavenger limits are higher than this value.

It is unlikely that a combination of radionuclides would be present in a consignment such that the borehole driller sum of fractions exceeded one due to concentrations of Ac-227, Cm-243 or Cs-137 close to the LLW definition and the other radionuclides present having high sum-of-fractions contributions. Ac-227, Cm-243 or Cs-137 could contribute no more than 0.29, 0.03 and 0.07 to the sum of fractions respectively, as these are the contributions if the activity concentration were 4 GBq t<sup>-1</sup> for Cm-243 or 12 GBq t<sup>-1</sup> for Ac-227 or Cs-137. It is appropriate therefore to identify activity concentration limits for control purposes on the basis of assessed impacts to the informal scavenger receptor, combined with the definition of LLW.

The resulting values are given in Table 6.9. Radionuclides with limits less restrictive than the screening level of 300 GBq t<sup>-1</sup> are not listed and are included within the 'Other' category. The 'other' radionuclides include tritium, C-14, Co-60 and Sr-90.

**Table 6.9: Activity concentration limits applicable to all stack locations**

Radionuclide	Activity concentration limit	Radionuclide	Activity concentration limit
	GBq t <sup>-1</sup>		GBq t <sup>-1</sup>
Ag-108m	0.35	Pu-240	1.5
Am-241	2.6	Pu-241	77
Am-242m	3	Pu-242	1.5
Am-243	0.98	Pu-244	0.47
Cl-36	24	Ra-226	0.19
Cm-245	0.83	Tc-99	100
Cm-246	1.70	Th-229	0.39
Cm-248	0.15	Th-230	0.18
Cs-135	120	Th-232	0.11
Ho-166m	0.26	U-233	0.97
I-129	58	U-234	4.2
Nb-94	0.22	U-235	0.9

Radionuclide	Activity concentration limit	Radionuclide	Activity concentration limit
	GBq t <sup>-1</sup>		GBq t <sup>-1</sup>
Np-237	1.1	U-236	21
Pa-231	0.15	U-238	3.4
Pu-238	16	Others*	300
Pu-239	1.4		

\*Others exclude radionuclides of less than 3 months half-life.

There are 79 LLW streams in the LLW forward inventory that would have a sum-of-fractions value greater than one for the informal scavenger limits set out in Table 6.9, based on the activity data in the 2022 UKRWI and the packaging assumptions applied in our inventory derivation (see reference [116]). This corresponds to 67 HHISOs. There are just over 18,900 HHISOs of LLW in the LLW forward inventory.

For most of the LLW streams with a sum-of-fractions value greater than one for the informal scavenger limits, there is not enough waste in the stream to fill one HHISO. We assess each stream against the constraints assuming that each container holds 45% waste and 55% grout [4]. This means there is more waste in the assessed container than is expected to arise (based on UKRWI volumes). In practice, these wastes would likely be combined with other streams and therefore may not fail the limits (heterogeneity within containers is discussed in Subsection 6.5.1).

Waste streams with more than one HHISO of waste that have a sum-of-fractions value greater than one include the following:

- non-compactable decommissioning waste from Amersham (less than two containers);
- residual waste from metal treatment of wastes from several sites 59 containers from 25 streams, including 40 containers estimated to arise from nuclear new build;
- Winfrith minor facilities decommissioning waste (less than two containers).

The largest of these streams only contains enough waste to require nine HHISOs. In our inventory derivation, we cautiously assume all activity associated with metal waste that undergoes treatment remains in the proportion of residual waste assigned to LLWR for disposal. Activities may be lower in practice. The activity of LLW arising from the new build programme is very uncertain, as discussed in reference [4]. Therefore, some of these wastes may have a sum-of-fractions value lower than one in practice.

All LLW streams with a sum of fractions greater than one for the borehole driller case also have a sum of fractions greater than one for the informal scavenger case, demonstrating that

consideration of the informal scavenger case alone is sufficient to control impacts to a borehole driller for LLW.

We therefore conclude that very few LLW streams would require control on the basis of the values in Table 6.9. This is because, for many radionuclides, the 4 and 12 GBq t<sup>-1</sup> LLW limits provide sufficient control.

Our current emplacement strategy includes a requirement that consignments with a sum-of-fractions value greater than one for the Beach Scavenger (the 2011 equivalent of the informal scavenger assessed in the 2026 ESC) must not be co-located. No more than one such consignment can be placed in a single stack or adjacent to another stack containing such wastes. We believe that this remains an appropriate strategy for ensuring that exposures would be limited in accordance with regulatory guidance, noting the following important factors.

- The assessment cases include assumptions about the time spent adjacent to the exposed wastes (discussed below) and in effect exposure to multiple consignments. It is reasonable to consider that the above activity concentration limits should be applied as an average over a number of consignments.
- As discussed above, examination of inventory data indicates that the frequency of arising of consignments that exceed the criteria is very low. There is therefore a very low probability of an informal scavenger encountering one, or more, such consignments.
- There are significant conservatisms in the assessment used to derive the informal scavenger limits including:
  - The dominant mode of exposure is associated with the time spent near exposed wastes, assumed to be 50 hours per year spent very close to the wastes during repeated visits to the area of erosion adjacent to the vaults and that such exposures occur for a number of years. Whilst this is considered a cautious basis for assessment purposes, it is considered too conservative to be used as an appropriate basis to control acceptance of wastes given the very low number of potentially significant consignments.
  - The assessment also assumes that all the activity associated with disposed wastes is retained with the wastes both prior to and during erosion.
- Consideration also needs to be given to the other three events in the assessment that are relevant for wastes at any stack height, namely the borehole driller, laboratory analyst and organised scavenger events. The activity concentration limits values calculated for the events are for most radionuclides less restrictive than for the informal scavenger, as discussed above. As for the informal scavenger, for all these events, averaging over a number of consignments is reasonable. For the borehole driller, for example, exposure is assessed on the basis of five boreholes drilled through the full depth of the cap and wastes, equivalent to a few tens of

consignments. Given the very low frequency of occurrence of the higher activity consignments, it is not considered credible that they would be exposed to such wastes for more than a small fraction of the time assumed as basis for their derivation. It can be concluded therefore that these receptors are also adequately protected by this approach, with measures taken to further minimise potential exposures by ensuring the more limiting consignments are not located in the same stack.

On this basis, we intend to maintain our current waste emplacement strategy. We will use the revised activity concentration limits in Table 6.9 to assess each consignment received, and will apply the emplacement strategy to any container that has a sum of fractions exceeding one.

The activity concentration limits derived in the human intrusion assessment are based on an assumed waste density of  $1.7 \text{ t m}^{-3}$ . This is based on the average density of packaged waste in the repository after capping, calculated using the Stage 2 Reference Inventory. The density ranges from  $1.6$  to  $1.8 \text{ t m}^{-3}$  across the different vaults. As part of our annual review process, we compare waste receipts to assumptions made in the ESC. If average vault densities were to deviate significantly from the value assumed when deriving the human intrusion limits, we would consider revising the limits to reflect updated understanding.

#### **6.4.1.2 Human Intrusion Derived Controls - Applicability to ILW**

Our current waste emplacement strategy is appropriate for managing impacts from LLW. However, it places reliance on the activity concentration definition of LLW. If a decision was taken to accept ILW in addition to LLW, we would need an alternative approach for ensuring impacts via human intrusion are consistent with regulatory guidance. We would apply the same revised approach to LLW and ILW, if a decision was taken to accept ILW.

We have investigated the effect of applying the  $300 \text{ GBq t}^{-1}$  threshold if a decision was taken to accept ILW to determine whether it would be unduly constraining. We have applied the activity concentration limits derived in the human intrusion assessment to all ILW in the 2022 UKRWI, excluding any waste that would never be sent to the LLWR, for example because it is covered by Scottish Higher Activity Waste Policy. We have investigated the following alternative approaches:

- 1) application of the  $300 \text{ GBq t}^{-1}$  threshold to group radionuclides with a limit above  $300 \text{ GBq t}^{-1}$  into 'other';
- 2) application of all limits derived in the human intrusion assessment regardless of their value, with the capacity for any radionuclides not assessed set to  $300 \text{ GBq t}^{-1}$ ;
- 3) application of all capacities derived in the human intrusion assessment regardless of their value, with the capacity for any radionuclides not assessed set to an arbitrary higher value of  $3,000 \text{ GBq t}^{-1}$ .

Using the first approach, 290 streams, corresponding to around 73,970 containers of ILW, had a sum-of-fractions value less than one for each of the informal scavenger, borehole

driller and laboratory analyst (applied separately). This increased to 339 ILW streams (around 76,010 containers) for the second approach and 371 ILW streams (around 77,210 containers) for the third approach.

On this basis, we would use the limits for the full set of radionuclides assessed in the human intrusion assessment. The increase in ILW passing the constraints is less significant when the limit used for radionuclides not assessed is increased. On this basis, we would retain a limit of 300 GBq t<sup>-1</sup> for radionuclides not assessed in the human intrusion assessment. If waste producers wished to send waste with high activity of such radionuclides, we could consider a bespoke assessment to identify whether the waste was suitable for disposal. If we received a significant volume of such requests, we could consider a basis for increasing the capacity for these radionuclides, which could involve:

- amending the half-life below which radionuclides are considered unlimited, noting that human intrusion assessments could not occur before the end of the PoA so setting this at 3 months is very cautious;
- increasing the range of radionuclides we assess and derive capacities for, accounting for the radionuclides of interest to waste producers.

As we would not be applying a screening threshold, it would no longer be appropriate to only use the informal scavenger limits, as the borehole driller event is the most restrictive for twelve radionuclides and the laboratory analyst event is most restrictive for two radionuclides (see Table 6.5). We have assessed all ILW streams in the UKRWI (excluding those that would never be sent to LLWR as noted above) against each of the limits separately and against a set of combined limits in which the most restrictive limit from the three events is selected for each radionuclide. Around 230 containers have a sum of fractions less than one when each event considered separately, but have a sum of fractions greater than one if the most restrictive limit from each event is used. All 230 containers are associated with a single waste stream, Miscellaneous Plants Initial/Interim Decommissioning: Ponds (2D115), which is a Sellafield stream that will arise from the decommissioning of spent fuel storage ponds. The UKRWI data sheet for the stream notes that the volume uncertainty varies from -30% to +200% and the activity uncertainty is stated as a factor of 10. The specific activity of consignments may therefore be quite different to the value used in our calculations. As this is the only stream for which combining the limits has a limiting effect, we consider it appropriate to combine the limits from the three human intrusion events into a single set using the most restrictive value for each radionuclide.

If a decision were taken to accept ILW in addition to LLW, rather than using the human intrusion limits to inform a waste emplacement strategy, we would use the limits to determine what waste consignments could be accepted. The limits would replace the current WAC requirement that waste meets the UK definition of LLW.

Specific activity is defined in our WAC as the activity of the consignment divided by the gross weight of the consignment, which includes the waste and the disposal container. As discussed above, the limits were derived on the basis of activity concentration in the final

waste packages, including the waste, grout and disposal container. If we were to apply the limits based on the packaged volume (without grout) there are around 17,900 containers that would exceed the constraint that would otherwise be acceptable once the weight of the grout was included. It would therefore not be appropriate for the limits to be applied to the waste and disposal container alone.

Some ILW containers would likely be grouted prior to transport to the LLWR, so could be assessed against the limits on the appropriate basis. However, some ILW may be received prior to grouting and all LLW will be grouted at LLWR as per current practice. To avoid complexity we would apply limits on the basis of GBq m<sup>-3</sup> rather than GBq t<sup>-1</sup>. We would use the waste density assumed in the calculations of the limits to convert GBq t<sup>-1</sup> to GBq m<sup>-3</sup>. We would continue to monitor average packaged waste densities in the vaults as part of our annual review and can consider revisions to our assessment if they deviate significantly from the density assumed in our human intrusion assessment.

**Table 6.10: Human intrusion limits if LLW and ILW were to be accepted**

Radionuclide	Limiting capacity GBq m <sup>-3</sup>	Radionuclide	Limiting capacity GBq m <sup>-3</sup>
Ac-227	71.4	Pu-238	27.2
Ag-108m	0.595	Pu-239	2.38
Am-241	4.42	Pu-240	2.55
Am-242m	5.1	Pu-241	130.9
Am-243	1.666	Pu-242	2.55
Cl-36	40.8	Pu-244	0.799
Cm-243	221	Ra-226	0.323
Cm-245	1.411	Tc-99	170
Cm-246	2.89	Th-229	0.663
Cm-248	0.255	Th-230	0.306
Cs-135	204	Th-232	0.187
Cs-137	289	U-233	1.649
Ho-166m	0.442	U-234	7.14

Radionuclide	Limiting capacity GBq m <sup>-3</sup>	Radionuclide	Limiting capacity GBq m <sup>-3</sup>
I-129	98.6	U-235	1.53
Nb-94	0.374	U-236	35.7
Np-237	1.87	U-238	5.78
Pa-231	0.255	Other	510

We would not expect any waste to have a sum-of-fractions value greater than one using this approach, as such wastes would be refused (or subject to a specific assessment via variation if considered appropriate). We therefore would not expect to need to apply a waste emplacement strategy on the basis of these constraints.

#### 6.4.1.3 Gaseous Releases

Limits on the amount of Ra-226 in a container can be used to control heterogeneity in the potential doses to people living in houses on the cap, and therefore the highest potential doses. We derive a limit on the total activity of Ra-226 in a container, based on the total radiological capacity for future waste in the whole repository (see Subsection 6.3.2) and the number of containers modelled as disposed. The limit, for the case when the geomembrane is intact and the cap vent is closed, is 49 MBq.

The distance of a container from the defect affects the time it takes radon to travel to the defect and hence the amount of decay that will occur before the radon reaches the house. Radon from containers at the top of a stack will have the shortest travel time and containers at the bottom of the stack will have the longest. As discussed in Subsection 6.4.2.1, we have derived limits on the activity concentration in containers in the top and bottom stack positions. The limit on activity concentration in the top and bottom container positions for Ra-226 is 0.36 MBq t<sup>-1</sup> (see Table 6.12). This equates to an activity limit of 14.4 MBq of Ra-226 for a 40 t HHISO. Therefore, the activity of Ra-226 in the upper stack position (closest to a possible defect) will always be less than the container limit derived from the radon gas assessment.

We propose to apply the following constraints to control heterogeneity in the potential doses from radon to people living in houses on the cap:

- the activity of Ra-226 in the top and bottom stack positions will be limited to 14 MBq;
- the activity of Ra-226 in containers that are not at the top or bottom of a stack will be limited to 50 MBq;
- containers bearing more than 50 MBq of Ra-226 would be subject to individual assessment via variation (see Subsection 8.3) and if accepted would be disposed on

top of a container in the bottom stack position (i.e. in stack position 2 if the container position 1 is the container at the bottom of the stack).

The above activity limits were derived based on a HHISO. If a decision was taken to accept ILW for disposal and the containers were of a different mass, we would derive a suitably scaled limit for ILW containers.

## 6.4.2 Controls on Upper-level Consignments

As discussed above, for some assessment cases and events, potential impacts are determined by the concentrations of radionuclides in the upper stack positions within the vault. Such cases include some of the human intrusion cases and external irradiation during the PoA. These are discussed below. Implementation aspects, including the basis for controls and waste emplacement, are discussed further in Section 8.

### 6.4.2.1 Human Intrusion

Our current emplacement strategy places restrictions on activity concentration in consignments that would be within 5 m of the surface of the cap [117]. Consignments that have a sum-of-fractions value greater than one for the human intrusion limits derived for upper stack position consignments as part of the 2011 ESC [25] are excluded from the top stack position and the bottom stack position<sup>24</sup> [117]. No more than one consignment with a sum of fractions greater than one can be placed in a given stack. We have considered whether our new human intrusion assessment implies any changes to our approach.

Of the human intrusion events [108], the trial pit excavator, construction worker, house occupier and smallholder events involve receptors that would only be exposed to upper layers of waste due to the depth of the excavations associated with these events. Activity concentration limits have been calculated for each of the four assessment events. The assessments results indicate that impacts to the trial pit excavator and construction worker receptors lead to calculated limits that, for all radionuclides, are less restrictive than for the other two events. The trial pit excavator and builder events are not therefore considered further. The limits derived for the house occupier and smallholder events, are given in Table 6.11. For each radionuclide the most restrictive value is shown in bold.

**Table 6.11: Radiological capacity values for house occupier and smallholder events**

Event	*House occupier	*Smallholder
Radionuclide	GBq t <sup>-1</sup>	GBq t <sup>-1</sup>
Ac-227	<b>1.4</b>	2
Ag-108m	<b>0.02</b>	0.0280

<sup>24</sup> The 'bottom stack' criterion is an optimisation measure to minimise saturation and releases from higher-activity containers.

Event	*House occupier	*Smallholder
Radionuclide	GBq t <sup>-1</sup>	GBq t <sup>-1</sup>
Am-241	1.8	3.6
Am-242m	1.4	2.7
Am-243	0.16	0.23
C-14	27	2.7
Ca-41	1.8 10 <sup>4</sup>	2.2
Cl-36	2	0.011
Cm-242	1,000	3,400
Cm-243	2.9	4
Cm-244	150	470
Cm-245	0.33	0.51
Cm-246	1.90	4.2
Cm-248	0.018	0.0240
Co-60	4,700	6,400
Cs-134	3.8 10 <sup>12</sup>	5.1 10 <sup>12</sup>
Cs-135	9.8	6.9
Cs-137	0.48	0.63
Eu-152	3.8	5.1
Eu-154	65	88
H-3	5.1 10 <sup>6</sup>	900
Ho-166m	0.018	0.025
I-129	7.9	0.14
Mo-93	310	2.8

Event	*House occupier	*Smallholder
Radionuclide	GBq t <sup>-1</sup>	GBq t <sup>-1</sup>
Nb-93m	1.8 10 <sup>5</sup>	<b>4.5 10<sup>4</sup></b>
Nb-94	<b>0.017</b>	0.023
Ni-59	1,800	<b>220</b>
Ni-63	400	<b>150</b>
Np-237	<b>0.14</b>	0.16
Pa-231	<b>0.051</b>	0.067
Pb-210	16	<b>0.7</b>
Pu-238	<b>5.2</b>	17
Pu-239	<b>2.2</b>	7.2
Pu-240	<b>2.2</b>	7.3
Pu-241	<b>53</b>	110
Pu-242	<b>2.2</b>	7.3
Pu-244	<b>0.067</b>	0.092
Ra-226	<b>3.6 10<sup>-4</sup></b>	3.8 10 <sup>-4</sup>
Ra-228	<b>1,300</b>	1,600
Ru-106	<b>1 10<sup>16</sup></b>	1.3 10 <sup>16</sup>
Sb-125	<b>4 10<sup>9</sup></b>	5.4 10 <sup>9</sup>
Sr-90	3.6	<b>1.2</b>
Tc-99	8.2	<b>0.23</b>
Th-228	<b>4.8 10<sup>13</sup></b>	6.4 10 <sup>13</sup>
Th-229	<b>0.085</b>	0.09
Th-230	<b>4 10<sup>-4</sup></b>	4.3 10 <sup>-4</sup>

Event	*House occupier	*Smallholder
Radionuclide	GBq t <sup>-1</sup>	GBq t <sup>-1</sup>
Th-232	<b>0.01</b>	0.013
U-233	<b>0.22</b>	<b>0.22</b>
U-234	<b>0.013</b>	0.014
U-235	<b>0.14</b>	0.18
U-236	25	<b>3.2</b>
U-238	<b>0.28</b>	0.33
Zr-93	<b>150</b>	<b>150</b>

\*The House occupier and Smallholder cases both use the lower end of the dose guidance level range (3 mSv/yr) since the events occur over prolonged periods.

The results also show that each of the two remaining events is the more restrictive for a significant number of radionuclides, with the smallholder event being more restrictive for radionuclides that dominate the ingestion pathway (e.g. C-14 and Cl-36) and the house occupier event being more restrictive for radionuclides that dominant external irradiation (e.g. Nb-94 and Ag-108m) and inhalation pathways (e.g. Ra-226 and Th-230).

There are two possible approaches to setting capacities. We could either:

- use two sets of values, based on the most restrictive value for each of the house occupier and smallholder events; or
- use a single set using the most restrictive value for each radionuclide from either event.

Whilst the latter is cautious, it is unlikely to lead to significantly greater numbers of consignments requiring emplacement management. Based on the LLW forward inventory and applying the LLW screening threshold of 300 GBq t<sup>-1</sup>, 7.2% of LLW containers would have a sum of fractions greater than one when the limits are applied separately and 7.3% would have a sum of fractions greater than one if a single set of limits with the most restrictive value from each event is used. As combining the limits into a single set does not have a significant impact on the number of containers expected to have a sum-of-fractions value greater than one, we will combine the revised smallholder and house occupier limits into a single set of limits. These are given in Table 6.12.

**Table 6.12: Radiological emplacement limits for upper stack position consignments**

<b>Radionuclide</b>	<b>Activity concentration limit GBq t<sup>-1</sup></b>	<b>Radionuclide</b>	<b>Activity concentration limit GBq t<sup>-1</sup></b>
Ac-227	1.4	Np-237	0.14
Ag-108m	0.02	Pa-231	0.051
Am-241	1.8	Pb-210	0.7
Am-242m	1.4	Pu-238	5.2
Am-243	0.16	Pu-239	2.2
C-14	2.7	Pu-240	2.2
Ca-41	2.2	Pu-241	53
Cl-36	0.011	Pu-242	2.2
Cm-243	2.9	Pu-244	0.067
Cm-244	150	Ra-226	0.00036
Cm-245	0.33	Sr-90	1.2
Cm-246	1.9	Tc-99	0.23
Cm-248	0.018	Th-229	0.085
Cs-135	6.9	Th-230	0.0004
Cs-137	0.48	Th-232	0.01
Eu-152	3.8	U-233	0.22
Eu-154	65	U-234	0.013
Ho-166m	0.018	U-235	0.14
I-129	0.14	U-236	3.2
Mo-93	2.8	U-238	0.28

<b>Radionuclide</b>	<b>Activity concentration limit GBq t<sup>-1</sup></b>	<b>Radionuclide</b>	<b>Activity concentration limit GBq t<sup>-1</sup></b>
Nb-94	0.017	Zr-93	150
Ni-59	220	Others*	300
Ni-63	150		

\*Others exclude radionuclides of less than 3 months half-life.

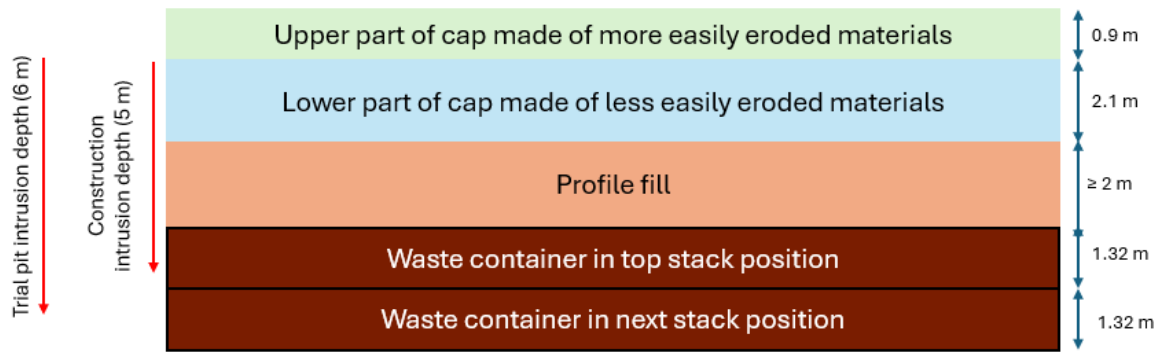
As expected, the values for upper level consignments in Table 6.12 are significantly more restrictive than the values in Table 6.11.

It is impractical to operate an emplacement strategy that takes into consideration averaging over a small number of consignments. We will therefore base the emplacement requirements solely on depth of intrusion.

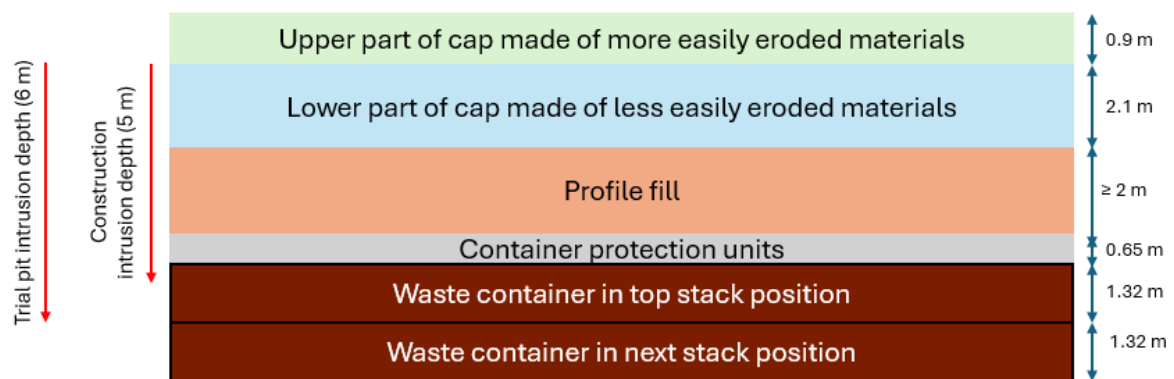
The closure engineering design has been revised since the 2011 ESC. As discussed in reference [5] the overall thickness between the top of the cap and the top of the wastes has been increased from a minimum of approximately 4 m to around 5 m (by increasing the depth of profile fill by 1 m) [118]. There are a few locations at the perimeter of Vault 8 that will have less than 2 m profile fill [13], however, waste is already in those locations so the capacities for future waste do not need to take this into account. In all other locations, the profile fill will be a minimum of 2 m [5].

The human intrusion assessment [108] notes that 1,000 years or more after cap placement, there could be localised thinning of the cap [13]. This is modelled as thinning by 1 m as the top 0.9 m of the cap will consist of materials that are more easily eroded. The cap thinning is taken into account in derivation of the limits by setting the thickness of cap and profile fill to a value of 4 m. The construction worker, smallholder and house occupier assessment events use an intrusion depth of 5 m. The trial pit excavator assessment event uses an intrusion depth of 6 m.

The thickness of the cap and profile fill and underlying layers are shown relative to intrusion depths in Figure 6.2 for existing and committed wastes and Figure 6.3 for wastes in strengthened containers (which would have a container protection unit on top of each stack).



**Figure 6.2: Intrusion for existing and committed waste**



**Figure 6.3: Intrusion for waste in strengthened containers, which will have container protection units on top of stacks**

For existing and committed waste the following would apply.

- If intrusion were to occur in an area where the cap is locally eroded at the surface, part of the container in the top stack position would be exposed by a construction activity (i.e. house building). At the highest possible trial pit depth, all of the top container in the stack and part of the container below it would be exposed.
- If the profile fill is more than 2.6 m thick, no intrusion would intercept the container below the top container.
- If the profile fill is more than 3.9 m thick, no intrusion could intercept waste.

For waste in strengthened containers:

- even if intrusion were to occur in an area where the cap is locally eroded at the surface, intrusion would only intercept part of the top container in a stack; and
- if the profile fill is more than 3.25 m thick, no intrusion could intercept waste.

On the basis of the above analysis, we propose to apply the following emplacement requirements to containers that have a sum of fractions greater than one for the constraints in Table 6.12.

- If the container has to be placed in an area of the vaults where the overall thickness between the top of the cap and the top of the wastes is less than 7 m:
  - the consignment must not be located at the top or the bottom of the stack (e.g. it must be placed at the equivalent of stack positions 2 and 3 for a four high stack of HHISOs and the equivalent of positions 2, 3 and 4 for a five high stack of HHISOs).
- Where possible, the container should be placed in a vault location at least 7 m below the top of the cap.

Using this approach, if a current container with a sum of fractions greater than one was placed directly below the top container, local surface erosion occurred and a trial pit was dug at the maximum feasible depth, there would be some waste with a sum of fractions greater than one exposed. However, the capacities for the trial pit case are less restrictive than the capacities shown in **Table 6.12** and only the top part of the container would be exposed. It would be disproportionate to account for this in our emplacement strategy, as we would be compounding several conservatisms. In addition, this is only an issue for waste in current containers. Only the top container in stacks of strengthened containers could be intercepted by any of the intrusion cases that affect upper stack levels, as the container protection unit increases the distance between the top of the waste and the surface.

We will continue to apply our current control identification system, as follows.

- LLWR Waste Acceptance Specialists use radionuclide data from the Waste Consignment Information and the ungrouted weight of each consignment to identify whether the consignment has the potential to have a sum of fractions greater than one.
- After grouting of the consignment, the sum of fractions is recalculated using the grouted weight of the consignment. If the sum of fractions is greater than one, the emplacement requirements above will be applied (see Subsection 8.4).

We have investigated whether our approach would need to change if we accepted ILW in addition to LLW. We have considered the effect of the house occupier and smallholder constraints on ILW in the UKRWI, excluding any waste:

- already packaged;
- that would never be routed to LLWR for other reasons, for example because it is covered by Scottish policy;

that fail one or more of the specific activity constraints that apply to all stack consignments (set out in Table 6.10) and therefore are unlikely to be accepted for disposal.

When the house occupier and smallholder constraints with the current screening threshold of 300 GBq t<sup>-1</sup> are applied separately, 95% of the ILW containers assessed have a sum-of-fractions value greater than one for one or both of the cases. Even if the screening threshold were increased to 10,000 GBq t<sup>-1</sup>, 95% of the ILW containers assessed are associated with

streams that have a sum-of-fractions value greater than one. Combining the constraints into a single set of capacities makes an insignificant difference to the number of containers that have a sum of fractions greater than one, regardless of the screening threshold applied.

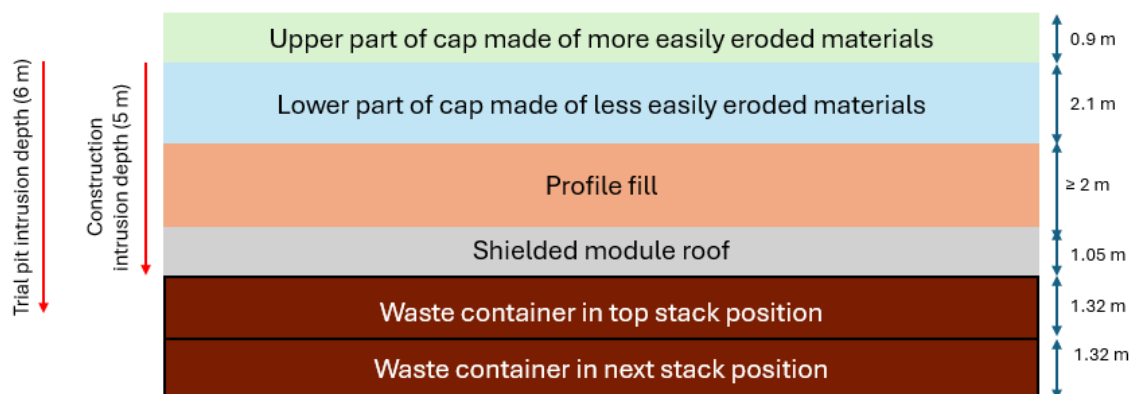
If a screening threshold is not applied (i.e. constraints derived for all radionuclides in the human intrusion assessment are used), 95% of the ILW containers assessed have a sum-of-fractions value greater than one for one or both of the cases. This is true regardless of whether the limit for any radionuclides not considered in the human intrusion assessment is set to 300, 3,000 or 10,000 GBq/t.

On this basis, we would retain the same emplacement limits as set out in **Table 6.12** if ILW were to be accepted in addition to LLW.

There are some waste streams that are unlikely to be acceptable for disposal at the LLWR as they contribute too much to radiological capacities. The Stage 3 Reference Inventory was derived by selecting ILW streams within the total radiological capacities used in the inventory derivation (note these were interim capacities, not those presented in this report), as described in reference [116]. Streams that are likely to be excluded due to a high radiological capacity contribution are therefore not in the Stage 3 Reference Inventory. 89% of the ILW containers in the Stage 3 inventory are associated with streams that have a sum-of-fractions value greater than one.

This analysis demonstrates that the majority of ILW that might be considered for disposal at the LLWR would have to be excluded from upper stack positions or placed in areas where the profile fill is deeper.

A proportion of this waste would have to be disposed in shielded modules (if accepted) due to high dose rates, as discussed in Subsection 6.4.2.2. As shown in Figure 6.4, waste in shielded modules would not be intercepted by an intrusion that is 5 m deep as the profile fill will be at least 2 m thick. However, the top container could be intercepted by an intrusion between 5 m and 6 m deep, if the thickness of the profile fill is less than 2.85 m.



**Figure 6.4:** Intrusion for waste in shielded modules

As a high proportion of ILW is likely to have a sum of fractions greater than one, it would be difficult to manage emplacement to avoid the potential for these wastes to be intercepted in an intrusion event. We have therefore concluded that the shielded modules should either:

- be located in an area of the vault that would be covered by at least 3 m of profile fill; or
- be lower than previously assumed such that containers are not within 7 m of the cap surface even if the profile thickness is 2 m.

For ILW not in shielded modules, there are likely to be too many containers that have a sum-of-fractions value greater than one to avoid placing the failing containers in the top stack location. It would therefore be difficult to apply the current emplacement strategy for these wastes, unless the waste could be inter-stacked with LLW containers. Other possible approaches are to:

- ensure no ILW containers are disposed in areas of the vaults where the profile fill thickness is less than 3.25 m;
- not stack ILW containers as high as LLW containers to avoid potential for the intrusion events to occur.

The latter is futureproof as it protects against changes to the cap design that could mean the intrusion events become possible (for example if the thickness of the profile fill was reduced for some reason after the waste was put in its disposal position). It may also be useful for reducing external doses (if this was necessary) as LLW containers would be higher than the neighbouring ILW containers.

#### **6.4.2.2 External Irradiation (PoA)**

Dose rates to workers and the public offsite are managed via operational practices and optimisation of the design of the disposal system. Doses to workers and offsite dose rates are currently low (40  $\mu$ Sv or less, see reference [14]) and we do not regularly receive containers that have dose rates that require special management. When higher dose rate wastes are consigned, additional measures are taken on an ad hoc basis to ensure doses to workers are ALARP.

The calculated peak annual external dose to the representative person from LLW is calculated to be 0.14 mSv when activity is averaged over all LLW in each vault [14]. However, there are some LLW streams forecast to be disposed that would require dose management if the activities at the time of receipt are as high as suggested in the 2022 UKRWI. The number of packages that could require dose management, when any such wastes might be sent to the LLWR and how high the package dose rates could be is uncertain.

Doses to offsite receptors during the PoA are dominated by external dose from direct irradiation where a direct line of sight is possible. Where there is no direct line of sight, for example due to topography of land, external irradiation by scattered radiation is the main

contributor to total dose at most times and receptor locations [105]. Containers attenuate radiation emitted from adjacent containers. The main contribution to external dose will therefore be from packages that are in direct line of sight of offsite receptors (direct radiation) and packages that are at the tops of waste stacks (scattered radiation). Offsite doses will therefore be highly dependent on the dose rates from waste containers at the edges of vaults and at the top of stacks. This includes:

- grouted containers in their final disposal position;
- grouted containers being stored (e.g. in warehouses) prior to moving them to their final disposal position;
- ungrouted containers received at the site, which are stored prior to grouting.

Storage locations for ungrouted containers will be managed based on operational practicality and any measures required to manage worker dose rates. Ungrouted containers are not routinely stacked above four high, so it is unlikely that ungrouted containers would be in direct line of sight of off-site receptors [14].

Given the uncertainty in the timing of potential receipt of higher dose rate packages, how high the dose rates might be and what operational approaches might be taken during storage in warehouses, we do not consider it appropriate to identify now a specific approach to managing LLW with high dose rates on the basis of our assessment of offsite doses.

However, our assessment provides a potential tool for identifying waste consignments that might require specific management arrangements. We have calculated peak doses from disposal of a unit activity concentration in each vault during the vault's operational period, assuming that the unit activity concentration is assigned at the start of its operational period. This is equivalent to assuming that the vault is full of containers each with a unit activity concentration at the start of operations. This is a different approach to that used to calculate doses from the reference inventory in the PoA assessment, in which inventory was allocated at a uniform rate with time over the filling period of the vault. We took the alternative approach when calculating peak doses to derive activity concentration limits to ensure that:

- the peak dose captured the potential for short-lived radionuclides to be located in all containers at the top and edges of the vaults at the same time (these peaks occur at the start of the vault filling period);
- the peak dose from ingrowth of daughters during the operating period was captured for any radionuclides where the daughter is the source of the external dose (these peaks would occur later in the vault filling period).

Disposal of a unit inventory in Vault 10 gave rise to the highest dose rate for all radionuclides. These values can be used to derive activity concentrations that would give rise to a specific annual dose rate, if all containers in the vault contained this activity concentration.

The PoA assessment uses the grouted waste mass (excluding the container mass<sup>25</sup>) to calculate average vault activity concentrations and hence doses to offsite receptors. The grout has the effect of reducing dose compared to if the calculation was carried out using mass of waste inside the container with no grout. This is appropriate for the assessment, as it focused on dose from grouted waste.

We have assessed LLW in the Stage 3 Reference Inventory against activity concentration limits derived using different dose rates as thresholds. The activity concentration used in the calculation is based on the mass of the waste and grout, excluding the container, for consistency with the approach taken when deriving the limits. The number of containers of waste failing the derived limits for different dose thresholds are shown in Table 6.13.

**Table 6.13: Number of grouted containers in the Stage 3 inventory failing limits based on different dose thresholds**

Annual dose the limits are based on (mSv)	Number of LLW containers in the Stage 3 inventory failing using this dose threshold (proportion of total LLW containers is shown in brackets)
0.03	5,828 (30%)
0.1	3,056 (16%)
0.2	2,684 (14%)
0.3	2,589 (14%)

As discussed in Subsection 6.1.5, offsite receptors receive doses from several pathways. The site-specific annual dose constraint of 0.3 mSv applies to doses from all pathways during the PoA. A lower dose rate threshold would therefore be appropriate for defining the limits, to avoid the potential for external dose rates to lead to offsite doses equal to the regulatory dose constraint. Using a threshold annual offsite dose of 0.2 mSv would ensure that this could not happen, without so many containers exceeding the sum of fractions that consideration of management options for such containers becomes impractical.

We could potentially also use a dose threshold to identify if containers:

- should not be disposed within direct line of sight of offsite receptors;
- should not be placed at the edges of warehouses closest to the site boundary;
- should not be placed at the top of stacks in warehouses.

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<sup>25</sup> Attenuation by the container walls was included in the model therefore the mass of the container is not included in the calculation of activity concentrations.

However, impacts to offsite receptors are only part of the consideration when deciding how to manage dose rates and where to emplace wastes, and implementation of an emplacement strategy can add significant operational complexity, especially when combined with other emplacement criteria. Assessment calculations indicate that the present day dose from external irradiation is 0.04 mSv and peak doses from the LLW inventory from external irradiation is 0.14 mSv. We therefore do not believe it is necessary to implement controls to manage external irradiation of off-site receptors at this time. We will keep this position under review, noting that the UKRWI includes some LLW with high activities of gamma emitting radionuclides and as there is uncertainty in the future inventory. We would implement activity concentration limits or alternative control measures if required in future. We will ensure that external irradiation is more of a general focus of design optimisation.

We will continue to monitor and assess doses to workers and members of the public. Dose rates at the site perimeter are measured on a quarterly basis as part of our monitoring programme, and analysed for adverse trends. We also analyse every update version of the UKRWI for its implications for the ESC, for example to determine whether there are any anticipated increase in key radionuclides contributing to external irradiation. Should dose rates start to increase or if consignors propose higher dose rate waste for disposal, there are several actions we could take to ensure doses to workers and the public remain as low as reasonably achievable. Our nuclear safety case and ESC teams would consider the optimised strategy for managing high dose rate waste at the time. Example approaches for managing high dose rate waste, if it arises, are listed below.

- We could adopt an emplacement strategy with higher dose rate containers placed in the centre and bottom layers of warehouses and vaults.
- We could ensure warehouses are not located in direct line of sight of offsite receptors, limit stack height within warehouses to ensure containers are not above the line of sight or consider some form of shielding of wastes in the warehouses if required.
- We could consider increasing the height of future vault walls or adding a separate shielding wall or berm to reduce direct dose, if it is deemed appropriate within wider design optimisation of future vaults.

If a decision was taken to accept ILW at the LLWR, waste with high external dose rates would be disposed in shielded modules.

Activity concentration limits based on the PoA external dose assessment are one potential way of determining which wastes would need to be placed in shielded modules. Table 6.14 shows the number of ILW containers in the Stage 3 inventory failing limits. based on different dose rate thresholds. This suggests that around 72% of the ILW in the Stage 3 inventory would have to be placed in shielded modules on the basis of the PoA assessment, assuming a dose threshold of 0.2 mSv. Operator dose assessments may require more of the waste to be in shielded modules, as operators may interact with containers of ungrouted waste. If a decision is taken to accept ILW for disposal at the LLWR, our ESC, Nuclear Safety Case and

Operational teams would work together to develop an approach to identifying if ILW consignments require disposal in shielded modules that protects both operators and offsite receptors.

**Table 6.14: Number of grouted ILW containers in the Stage 3 inventory failing limits based on different dose thresholds**

Annual dose is the limits are based on (mSv)	Number of ILW containers in the Stage 3 inventory failing using this dose threshold
0.03	22,774 (97%)
0.1	17,917 (76%)
0.2	16,865 (72%)
0.3	14,605 (62%)

Any ILW that did not require placement in shielded modules to manage external dose rates would be managed in the same way as LLW, as discussed above.

### 6.4.3 Summary of Controls on Consignments

Subsections 6.4.1 and 6.4.2 have derived a basis of controls for consignments. This leads to the following controls:

The identification of consignments that have a sum of fractions greater than one using the activity concentration limits set out in Table 6.9. Such consignments would be subject to an emplacement strategy that prevents them from being co-located.

- Consignments containing Ra-226 will be subject to the following controls:
  - the activity of Ra-226 in the top and bottom stack positions will be limited to 14 MBq;
  - the activity of Ra-226 in containers that are not at the top or bottom of a stack will be limited to 50 MBq;
  - containers bearing more than 50 MBq of Ra-226 would be subject to individual assessment via variation and if accepted would be disposed on top of a container in the bottom stack position.

The identification of consignments that need to be excluded from upper stack positions within the vaults. This is because of their potential importance in terms of exposure of persons who might live in a house or have a smallholding on the site following human intrusion into the wastes that leaves contaminated materials on the surface. We will identify these consignments using the activity concentration limits for each radionuclide in **Table 6.12**, using the sum-of-fractions methodology. All such consignments will then be managed as part of an emplacement strategy (Subsection 8.4). In addition, dependent on the results

of dose rate monitoring and around the site and ongoing analysis of the future inventory, consideration will be given to the need for an emplacement strategy for high dose rate consignments.

This approach is considered to be an appropriate system for the management of the acceptance of consignments and provides a sufficiently protective basis for control in accordance with the regulatory criteria. The application of these controls is discussed further in Section 8.

If a decision was taken to accept ILW in addition to LLW our approach to controlling consignments would be revised. We would apply the same activity concentration limits for all consignments, regardless of whether they had activities above or below the 4 and 12 GBq t<sup>-1</sup> definition of LLW.

- The limits set out in Table 6.10 would be applied to determine whether a consignment could be accepted for disposal. These limits would replace the current WAC requirement that the total Specific Activity of any Waste Consignment Consigned for disposal as Low Level Waste at the Low Level Waste Repository shall not exceed 4 GBq t<sup>-1</sup> for all alpha-emitting radionuclides and 12 GBq t<sup>-1</sup> for all other radionuclides.
- The container controls derived for Ra-226 are based on a HHISO. If ILW was accepted in containers of a different size, Ra-226 limits would be derived for those containers.

The limits in **Table 6.12** would be used to inform whether consignments needed to be excluded from the top stack position..

Our analysis indicates that additional emplacement controls are likely to be required for ILW:

Consignments with sums of fractions greater than one using the limits in **Table 6.12** would either need to be placed in areas of the vault where the profile fill is thick enough to prevent intrusion into these containers regardless of stack position, or stack heights would need to be reduced.

- Containers with high dose rates would be placed in shielded modules. We would develop an approach to identifying if ILW consignments require disposal in shielded modules that protects both operators and offsite receptors.

We would not require waste consignors to identify whether a consignment is classified as LLW or ILW in order to apply these controls.

## **6.5 Controls Applicable to Sub-Container Scale**

In addition to limits on the total quantities of radioactivity disposed of at the site and limits at a waste consignment scale, we have also considered requirements for limits on the quantities of radioactivity at a sub-container scale.

### 6.5.1 Heterogeneity of Activity

Non-uniform distribution of radionuclides, or heterogeneity of activity within waste, may result in elevated doses if exposure occurs to areas of higher specific activity waste. The current WAC [71] (§L3.2.3) specifies that the specific activity (defined as the activity divided by the gross weight of the consignment including the waste and the disposal container) *'must be a reasonable reflection of the Activity of the waste across the volume of the waste'*. Since this is subjective, we have undertaken work to develop a risk-based numerical control [119]. This could be implemented in addition to, or instead of, the 'reasonable reflection' criterion. Requirements for a consignor to demonstrate BAT [71] (§L1) and not to mix with other wastes solely for the purpose of re-categorisation of the waste [71] (§L3.2.3) would remain in force.

To develop the numerical control, we first considered which scenarios could result in people spending time in close proximity to exposed waste that is relatively unmixed with other materials. Relevant scenarios included human intrusion or deliberate interaction with waste following coastal erosion since interactions could be limited to relatively small volumes of waste. This is in contrast to other exposure pathways such as groundwater or gas mediated releases which would not be affected by heterogeneity at this scale because contaminants would be 'mixed' within the near field prior to any release.

The following scenarios were studied to develop the controls.

- The **Laboratory Analyst**, who we assume is exposed to material extracted by borehole drilling that penetrates through the cap. We consider exposure of the Laboratory Analyst to radioactivity from dust inhalation, inadvertent ingestion of radioactive material, external irradiation and exposure to radon and thoron. The analyst is assumed to examine eight core samples from the site, each for two hours, with one at the maximum allowable specific activity. The other seven are cautiously assumed to come from the disposal area that results in the highest total dose. The activity limits for each radionuclide for the Laboratory Analyst were calculated using the 20 mSv annual dose guidance level minus the dose from the seven other boreholes [119].
- The **Informal Scavenger**, who we assume regularly visits the area after coastal erosion has exposed parts of the LLWR site and, for example, stands examining the emerging waste items in the cliff face. We consider exposure of the Informal Scavenger to radioactivity from inhalation of contaminated dust, ingestion of contaminated materials and external irradiation. The Informal Scavenger visits the site for one hour per day for fifty days per year but only one of those visits involves remaining in proximity to waste at the maximum allowable specific activity. The other 49 hours scavenging are cautiously assumed to be in proximity to the vault cell that gave rise to the highest doses in the main human intrusion assessment [108]. The Informal Scavenger also takes an item of average activity home and spends one hour at a proximity of 1 m to the retrieved item for one hour per day whilst at home.

The activity limits for each radionuclide for the Informal Scavenger were calculated using the 3 mSv/yr dose guidance level minus the dose from the 49 other hours scavenging and from exposure to the item at home [119].

- The **Organised Retrieval** worker is part of a local material recovery or archaeological group who we assume visits the site after coastal erosion has exposed waste. We consider exposure of the Organised Retrieval worker to radioactivity from inhalation of contaminated dust particles, ingestion of contaminated materials and external irradiation from exposed waste. They work at the site for 8 hours per day for a total of 5 days. One of the working days is assumed to be in proximity to waste at the maximum allowable specific activity. The other 4 working days are cautiously assumed to be in proximity to the vault cell that gave rise to the highest doses in the main human intrusion assessment [108]. The activity limits for each radionuclide for the Organised Retrieval worker were calculated using the 20 mSv annual dose guidance level minus the dose from the 4 other working days [119].

We intend to consult with the Environment Agency on the approach, and with consignors on implementation practicalities before we finalise the activity limits. For example, the numerical controls on individual radionuclides could be used within a sum-of-fractions approach to assess the suitability of waste, radionuclides could be grouped, or generic alpha/non-alpha limits could be derived. A trade-off will always exist between approaches that are simple to implement and those that enable the widest range of waste to be safely accepted.

The current work has only considered LLW [119]. If we were to move to acceptance of ILW, we would need to further develop the approach.

### **6.5.2 Discrete Items**

A discrete item is considered to be a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and that could be a focus of interest, out of curiosity or potential for recovery and recycling/re-use of materials should the waste item be exposed after repository closure, for example by coastal erosion or some human intrusion event.

We consider casual and short duration encounters with discrete items against an effective dose of 20  $\mu$ Sv. We assess doses due to deliberate collection or interaction with discrete items exposed on the coast (assuming the receptor has no knowledge that the items are radioactively contaminated) against the dose guidance range applicable for human intrusion events. We take this approach as it is uncertain whether such interactions could occur and therefore not possible to assign a probability to such an encounter. We calculate discrete item limits for casual encounters with waste exposed by coastal erosion and for deliberate scavenging of materials exposed by coastal erosion. We do not calculate discrete item limits for other human intrusion cases, as the limits calculated in relation to coastal erosion will be bounding, as discussed in reference [15], where a full description of the two approaches is provided. These are summarised in Table 6.15.

**Table 6.15: Summary of approaches for assessing discrete items**

Item type	Event and key assumptions - Casual Encounter	Event and key assumptions - Deliberate interaction
Small item (up to 100g)	Recreational user undertakes casual inspection of items totalling one hour over the course of the year	A scavenger picks up a small item (up to 100 g) and puts it in their pocket or bag. They are exposed to the object at close proximity (0.3 m) for 16 hours.  A scavenger picks up a small item (up to 100 g) and displays it in their home. They are exposed at a distance of one metre for 4 hours a day throughout the year.
Medium size item (100 g to 1 kg)	Recreational user undertakes casual inspection of items totalling one hour over the course of the year.	The item is taken home and closely examined in a workshop or garage for two hours. The object is then placed on a shelf in the garage or workshop, after noting that the object has no functional value or ability to be repaired.
Large item (1 kg+)	Recreational user undertakes casual inspection of items totalling one hour over the course of the year.  'Visitor' uses item as a windbreak during six visits to the beach over the course of the summer.	Bound by casual visitor and impacts and limits derived from general scavenging.

Our assessment of informal scavenging of discrete items is highly speculative, for the following reasons.

- Our experience shows that these are a very small proportion of discrete items received [107].
- Items are far more likely to be of interest to 'casual inspection' than deliberate scavenging. By nature, the items are waste from decommissioning and operational plant and will not have direct value for re-use or be particularly interesting or novel.
- Whilst the repository near field will inhibit degradation, waste will have experienced a degree of degradation which will accelerate upon exposure, further reducing the potential for scavenging whilst maintaining the potential for casual interest.

A comparison of the limits derived from casual inspection and deliberate interaction is provided in Table 6.16 with the lower limit emboldened. These are activities at the time of disposal.

**Table 6.16: Comparison of limits derived from casual inspection [107] and deliberate interaction [108] events**

Radionuclide	Activity Limit (GBq)			
	Small Item (10 g) Deliberate Interaction*	Small Item (10 g) Casual Inspection*	Medium Item (1 kg) Deliberate Interaction*	Medium Item (1 kg) Casual Inspection*
Ac-227	3	100	300	100
Ag-108m	<b>0.03</b>	0.001	0.01	<b>0.001</b>
Am-241	<b>0.003</b>	0.01	0.3	<b>0.01</b>
Am-242m	<b>0.003</b>	0.01	0.3	<b>0.01</b>
Am-243	0.003	<b>0.001</b>	0.03	<b>0.001</b>
C-14	<b>0.3</b>	<b>0.3</b>	10	<b>0.3</b>
Ca-41	<b>3</b>	<b>3</b>	1,000	<b>3</b>
Cl-36	0.3	<b>0.01</b>	0.3	<b>0.01</b>
Cm-242	<b>3</b>	<b>3</b>	1,000	<b>3</b>
Cm-243	<b>0.3</b>	3	30	<b>3</b>
Cm-244	0.3	<b>0.001</b>	100	<b>0.001</b>
Cm-245	<b>0.001</b>	0.01	0.03	<b>0.01</b>
Cm-246	<b>0.003</b>	0.01	0.3	<b>0.01</b>
Cm-248	<b>3 10<sup>-4</sup></b>	0.001	0.003	<b>0.001</b>
Co-60	3 10 <sup>6</sup>	<b>100</b>	1 10 <sup>6</sup>	<b>100</b>
Cs-134	3 10 <sup>6</sup>	<b>100</b>	1 10 <sup>6</sup>	<b>100</b>
Cs-135	<b>0.3</b>	<b>0.3</b>	3	<b>0.3</b>
Cs-137	30	<b>3</b>	30	<b>3</b>
Eu-152	1 10 <sup>5</sup>	<b>100</b>	3 10 <sup>4</sup>	<b>100</b>

Radionuclide	Activity Limit (GBq)			
	Small Item (10 g) Deliberate Interaction*	Small Item (10 g) Casual Inspection*	Medium Item (1 kg) Deliberate Interaction*	Medium Item (1 kg) Casual Inspection*
Eu-154	3 10 <sup>7</sup>	<b>100</b>	1 10 <sup>7</sup>	<b>100</b>
H-3	3 10 <sup>8</sup>	<b>100</b>	3 10 <sup>10</sup>	<b>100</b>
Ho-166m	0.03	<b>0.001</b>	0.01	<b>0.001</b>
I-129	<b>0.003</b>	0.01	1	<b>0.01</b>
Mo-93	<b>0.03</b>	0.3	30	<b>0.3</b>
Nb-93m	1 10 <sup>6</sup>	<b>100</b>	3 10 <sup>8</sup>	<b>100</b>
Nb-94	0.01	<b>0.001</b>	0.003	<b>0.001</b>
Ni-59	<b>3</b>	<b>3</b>	300	<b>3</b>
Ni-63	30	<b>3</b>	300	<b>3</b>
Np-237	0.003	<b>0.001</b>	0.03	<b>0.001</b>
Pa-231	<b>3 10<sup>-4</sup></b>	0.001	0.03	<b>0.001</b>
Pb-210	<b>3</b>	100	1,000	<b>100</b>
Pu-238	<b>0.03</b>	0.3	10	<b>0.3</b>
Pu-239	<b>0.001</b>	0.01	0.3	<b>0.01</b>
Pu-240	<b>0.001</b>	0.01	0.3	<b>0.01</b>
Pu-241	<b>0.03</b>	0.3	10	<b>0.3</b>
Pu-242	<b>0.001</b>	0.01	0.3	<b>0.01</b>
Pu-244	<b>0.001</b>	<b>0.001</b>	0.03	<b>0.001</b>
Ra-226	<b>3 10<sup>-4</sup></b>	0.001	0.003	<b>0.001</b>
Ra-228	3 10 <sup>5</sup>	<b>100</b>	3 10 <sup>6</sup>	<b>100</b>

Radionuclide	Activity Limit (GBq)			
	Small Item (10 g) Deliberate Interaction*	Small Item (10 g) Casual Inspection*	Medium Item (1 kg) Deliberate Interaction*	Medium Item (1 kg) Casual Inspection*
Ru-106	3 10 <sup>6</sup>	<b>100</b>	3 10 <sup>6</sup>	<b>100</b>
Sb-125	1 10 <sup>7</sup>	<b>100</b>	1 10 <sup>7</sup>	<b>100</b>
Sr-90	<b>30</b>	100	30	<b>100</b>
Tc-99	<b>0.3</b>	<b>0.3</b>	3	<b>0.3</b>
Th-228	3 10 <sup>5</sup>	<b>100</b>	3 10 <sup>6</sup>	<b>100</b>
Th-229	<b>3 10<sup>-4</sup></b>	0.001	0.03	<b>0.001</b>
Th-230	<b>3 10<sup>-4</sup></b>	0.001	0.03	<b>0.001</b>
Th-232	<b>3 10<sup>-4</sup></b>	0.001	0.003	<b>0.001</b>
U-233	<b>0.003</b>	0.01	0.3	<b>0.01</b>
U-234	<b>0.003</b>	0.01	1	<b>0.01</b>
U-235	<b>0.003</b>	0.01	0.03	<b>0.01</b>
U-236	<b>0.003</b>	0.01	1	<b>0.01</b>
U-238	<b>0.003</b>	0.01	0.03	<b>0.01</b>
Zr-93	<b>0.3</b>	3	30	<b>3</b>

\* Comparison of limits derived from casual inspection [107] and deliberate interaction [108] events (the lower limit is emboldened). Deliberate interaction limits are based on the mean of the 'surface contaminated' and 'volumetrically contaminated' limits in reference [108]

The calculated activity limits from deliberate interaction are typically similar to those from casual encounters, or the limits for casual encounters are more restrictive.

We consider it appropriate to base the discrete item control on a casual encounter, as it currently is in the WAC. We are proposing a new group, Group D, which includes short-lived radionuclides that will have a higher limit. The limits, with updated Group C and D limits, are shown in Table 6.17. Previously, the limit for Group C had been curtailed in order to discourage inappropriate mixing and dilution, but we consider this is best aspects by other means, such as the 'reasonable reflection' criterion (L3.2.3), limits on consignment dose

rates (L), requirements on the application of BAT (L3.2.1), and Environment Agency advice to consignors on mixing and dilution. This ensures the focus of the discrete item control is on environmental safety.

**Table 6.17: Updated discrete item limits [107]**

Radionuclide	Weight 1 kg or less	Weight between 1 kg and 100 kg	Weight 100 kg or greater
Group A	0.001 GBq	1 GBq t <sup>-1</sup>	0.1 GBq
Group B1	0.01 GBq	10 GBq t <sup>-1</sup>	1 GBq
Group B2	0.3 GBq	300 GBq t <sup>-1</sup>	30 GBq
Group C	3 GBq	3000 GBq t <sup>-1</sup>	300 GBq
Group D	100 GBq	100,000 GBq t <sup>-1</sup>	10,000 GBq

Table 6.18 shows a comparison of proposed group allocations with the current WAC. This shows that most radionuclides are in the same group as present, but some have moved to a less restrictive group. This is mainly due to the longer period of decay assumed<sup>26</sup>. The only exception is Cl-36, which has moved to a more restrictive group. This is due to updated understating of the dosimetry for Cl-36.

**Table 6.18: Updates to radionuclide groupings [107]**

Radionuclide	Potential new group	WAC 5.0 group	Radionuclide	Potential new group	WAC 5.0 group
Ac-227	D	B2	Ni-63	C	C
Ag-108m	A	A	Np-237	A	A
Al-26	A	-	Pa-231	A	A
Am-241	B1	B1	Pb-210	D	B2
Am-242m	B1	B1	Pd-107	C	-
Am-243	A	A	Po-210	D	-
Be-10	B1	-	Pt-193	D	-

<sup>26</sup> We now assume disposal within the next ten years, rather than at the end of operations, providing approximately 100 years of additional decay. The limits will be reviewed and updated as part of an ESC major review.

<b>Radionuclide</b>	<b>Potential new group</b>	<b>WAC 5.0 group</b>	<b>Radionuclide</b>	<b>Potential new group</b>	<b>WAC 5.0 group</b>
Bi-210m	A	-	Pu-238	B2	B1
C-14	B2	B2	Pu-239	B1	B1
Ca-41	C	B2	Pu-240	B1	B1
Cl-36	B1	B2	Pu-241	B2	B2
Cm-242	C	-	Pu-242	B1	B1
Cm-243	C	B2	Ra-226	A	A
Cm-245	B1	B1	Ra-228	D	-
Cm-246	B1	B1	Se-79	B2	-
Co-60	D	C	Sm-151	D	C
Cs-135	B2	B2	Sn-121m	D	-
Cs-137	C	B2	Sn-126	A	A
Eu-152	D	C	Sr-90	D	B2
H-3	D	C	Tc-99	B2	B2
Hf-178m	C	-	Th-228	D	-
Ho-163	D	-	Th-229	A	A
Ho-166m	A	-	Th-230	A	A
I-129	B1	B1	Th-232	A	A
La-137	B2	-	U-232	B1	B1
Mo-93	B2	B2	U-233	B1	B1
Nb-91	B2	-	U-234	B1	B1
Nb-92	A	-	U-235	B1	B1
Nb-93m	D	C	U-236	B1	B1

Radionuclide	Potential new group	WAC 5.0 group	Radionuclide	Potential new group	WAC 5.0 group
Nb-94	A	A	U-238	B1	B1
Ni-59	C	C	Zr-93	C	B2

In reference [15], we also show that the discrete item control has been effective in its purpose since it was introduced, which is to ensure that disposals do not increase exposure to discrete items in a manner that would significantly increase the general dose from recreational use of the beach. These conclusions hold for disposal of ILW. As an additional control, we propose to undertake annual monitoring and trending (Subsection 3.4) of disposals of discrete items to ensure this remains the case.

### 6.5.3 Active Particles

An active particle is a particle in the size range of 0.6 to 2.0 mm of high-specific activity material. As for discrete items, active particles present at the LLWR may be exposed as a result of coastal erosion or some human intrusion event. A key aspect of particles relative to discrete items is that particles are not obviously observable in the environment. Hence, human interactions with particles are usually inadvertent. That is, the human interacting with the particle is not aware that they are doing so. For the particles assessment, exposures to particles are assumed to take place as part of the smallholder event. As particles are assessed for the smallholder event (a long-term exposure), it is appropriate to compare the assessed doses against the lower range of the annual dose guidance level (3 mSv).

The Human Intrusion Assessment [108] shows that for all particle types and intruded vaults or trenches, none of the assessed effective doses exceed the annual dose guidance level of 3 mSv. This is in spite of the highly cautious assumption used in the assessment, that assumes the radionuclide inventory in each grid cell is present in the form of 1 mm particles and that all particle types are present.

It is not practical to prevent every single active particle entering the LLWR. There is always the possibility of a single or few active particles in a waste consignment because it is not possible to characterise and monitor wastes to identify all active particles. Waste consignors are obliged to consider the possibility that a waste may contain such particles. This is captured by the current WAC L3.2.5 [71], which requires a variation for any waste containing, or that may contain, active particles, or materials that may break down into active particles. As a result of the 2026 ESC assessments, we do not propose to change the approach or the WAC for active particles.

### 6.5.4 Low-activity Sources

The current limits on low-activity sources (L3.2.4) were established following an assessment conducted as part of the 2011 ESC [25, 120]. That work reviewed historical disposals to establish typical radionuclides involved, and then identified the situations that bound risk:

either an individual inspecting an intact grouted source container found on the beach, or a person picking up an individual source and potentially carrying it in a pocket or keeping it at home. The assessment set 'grouped' activity limits using a similar approach as for discrete items (Subsection 6.5.2).

Beyond establishing activity limits for individual sources and for source containers, L3.2.4 specifies several qualitative requirements intended to minimise exposure potential and ensure clarity of record-keeping. Consignors must remove as much extraneous packaging as practicable, and where a source might be visually appealing or appear potentially useful, it should be deliberately disfigured to reduce the likelihood that someone finding it on a beach would be tempted to pick it up. The sources must then be mixed with sufficient cement grout inside a clean paint-tin-type container, with the container filled fully to eliminate voids. This ensures each source is encapsulated, provides basic shielding (particularly for beta emitters), prevents buoyancy in marine environments, and reduces the chance of the container being crushed or ruptured as it degrades.

Whilst similar to the assessment of discrete items, the sources assessment includes further subtleties such as the contribution of the 'paint tin' when considering multiple sources. The two sets of limits are therefore not directly comparable.

Currently, the WAC for sealed sources includes limits for radionuclide 'groups' of similar hazard. These groups mirror those for discrete items (L3.2.3). Since the WAC for sealed sources was introduced, the only relevant changes to our understanding are the dose factors and coefficients [113]. These are taken account in the updated calculations for discrete items, which also now takes account of radioactive decay during the operational period. We have not identified any other changes to our conceptual understanding or underlying data that would suggest a wider update of the control for sealed sources or its underlying assessment is required. Therefore, we propose to retain the current WAC whilst modifying the radionuclide grouping to mirror the updates to discrete item groups according to Table 6.18. This retains the current approach whilst taking account of updates to the underlying data.

## **6.6 Fissile Controls**

Small quantities of fissile materials are present within the LLW disposed of at the LLWR. WAC [71] have been in place for many years to ensure that an accidental neutron chain reaction, that is a criticality accident, cannot arise as a consequence of the presence of these small quantities of fissile material within wastes sent to the LLWR.

The criticality safety assessment has been revised as part of the 2026 ESC [121]. The methodology adopted for the assessment incorporates elements of 'relevant good practice' from the ISO standard on criticality safety [122] and from guides and standards published by the IAEA [123, 124]. The assessment follows our criticality safety principles [125]. The assessment demonstrates that a criticality accident cannot occur as a result of either current

LLWR operations (including potential accident conditions) or the future evolution of the LLWR after site closure [126, 127, 128].

The assessment findings follow.

- Explicit additional fissile limits at repository level are not required because compliance with the WAC fissile limits already ensures consignments remain well below Safe Fissile Mass values. The CSA demonstrates, using pessimistic modelling, inventory analysis and post-closure behaviour, that even under bounding conditions the fissile materials remain too small in quantity, too dispersed and too diluted to form critical configurations.
- Criticality safety is demonstrated based on the fissile limits defined in the WAC. These WAC limits cap the quantities of enriched uranium and plutonium that may be consigned, and the CSA confirms that consignments compliant with these limits remain safely subcritical under all operational and post-closure scenarios assessed.
- The fissile material is dispersed throughout large volumes of other waste materials which provide sufficient dilution of the fissile material to ensure that criticality is physically impossible.
- The post-closure design features of the LLWR will passively control the emplaced fissile materials and minimise water rate into the repository, so that only very gradual changes will take place post-closure and the actions of groundwater flows will not lead to criticality.
- The long-term transport of fissile material within the repository and from the repository to the underlying far-field geology will be limited to quantities too small to give any significant possibility of a criticality.
- The repository is liable to be disrupted by coastal erosion within a time frame of several hundred to a few thousand years. Even if increased water penetration to the wastes were possible due to coastal erosion, the nature and quantities of the wastes are such that critical accumulations are not credible.

We therefore propose to retain the fissile controls as currently defined in the WAC.

## 7 Controls to Limit Non-radiological Inventory

Another key component of the WAC is the setting of controls to limit the quantities of non-radiological contaminants which may be disposed of in a facility. The objective of this section is to define the controls to limit the non-radiological inventory. As with the radiological controls discussed in Section 6, our controls derive from, or are informed by, our assessment model outputs.

When setting controls, we have considered Principle 3 and Requirement R10 of the GRA. Principle 3 necessitates the provision of a level of protection '*consistent with that provided by the national standard at the time of disposal for wastes that present a non-radiological but not a radiological hazard*'. Requirement R10 notes that, while national standards for the disposal of hazardous waste may not be suitable to apply to waste that presents both radiological and non-radiological hazards, '*a level of protection should be provided against the non-radiological hazards that is no less stringent than would be provided if the standards were applied.*' [20] (§6.4.2).

The relevant standards to consider when demonstrating that disposals of solid radioactive waste at the LLWR address Principle 3 and Requirement R10 are the following.

- The European Union Water Framework Directive 2000/60/EC and its daughter directive, the Groundwater Daughter Directive 2006/118/EC. Both directives are concerned with the protection of groundwater against pollution, the prevention and limitation of inputs of pollutants to groundwater and the prevention of deterioration of status of groundwater bodies. In England, the Water Framework Directive and the Groundwater Daughter Directive are implemented by:
  - the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017;
  - the groundwater provisions in Schedule 22 of the Environmental Permitting (England and Wales) Regulations 2016.
- The requirements on acceptance of asbestos to a disposal facility set in Environment Agency guidance *Landfill Operators: Environmental Permits* [129]. This is based on EU Council Decision 2003/33/EC establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC on the landfill of waste [130].

We therefore consider the impacts of non-radiological contaminants to groundwater and impacts arising from the disposal of asbestos when setting controls on the acceptance of non-radiological contaminants. We have also considered the impacts arising from flammable and chemotoxic gases generated by waste degradation processes.

As discussed in reference [131], a hazardous landfill operator would not be required to assess non-radiological impacts arising from the coastal erosion and human intrusion pathways. We have not, therefore, considered these pathways when determining controls on non-radiological contaminants.

## 7.1 Approach to Managing Non-radiological Contaminants

We undertook work after the 2011 ESC to develop our approach to managing non-radiological contaminants, which formed the basis of our WAC. In our WAC, we considered the following three categories of non-radiological contaminants which include hazardous waste, hazardous substances and non-hazardous pollutants.

- **Category 1** - materials for which we record the masses, but do not manage against a numerical capacity.
- **Category 2** - materials for which we record the contaminant masses, and manage disposals against a numerical capacity derived from our groundwater assessment model.
- **Category 3** - materials which would be categorised as hazardous waste<sup>27</sup> if they were not radioactive, hazardous substances, or non-hazardous pollutants, and which would only be accepted for disposal after receipt of a variation and completion of an assessment to demonstrate that disposal at the LLWR is consistent with the ESC.

The classification of materials to the three categories was based on the degree of impact that the material would have on the natural environment, as indicated in the then-current Joint Agency Groundwater Directive Advisory Group guidance [132]. The classification takes into consideration whether it is appropriate and proportionate to manage disposal of a given contaminant against a capacity limit.

## 7.2 Current Category 1 and Category 2 Contaminants

### Category 1

In our current WAC, the following contaminants are assigned to Category 1:

- aluminium metal/alloy;
- asphalt or tarmac not containing coal tar (generally that laid down post-1980);
- bitumen;
- chromium metal/alloy;
- cobalt metal/alloy;
- copper metal/alloy;

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<sup>27</sup> Note that in the current WAC this excludes asbestos and man-made fibres, which we discuss in Subsection 7.4.

- fluoride (inorganic);
- iron metal/alloy;
- magnesium metal/alloy;
- mild steel;
- molybdenum metal/alloy;
- nickel metal/alloy;
- phenol;
- phosphate;
- plastics (halogenated);
- plastics (non-halogenated);
- stainless steel;
- tin metal/alloy;
- titanium metal/alloy;
- vanadium metal/alloy;
- vinyl chloride (un-polymerised);
- zinc metal/alloy.

## **Category 2**

In our current WAC, the following contaminants are assigned to Category 2:

- arsenic all forms;
- asphalt or tarmac containing coal tar (generally that laid down pre-1980);
- beryllium all forms;
- boron all forms;
- cadmium metal/alloy;
- cyanide;
- lead metal/alloy;
- mercury metal/alloy;
- selenium all forms;
- tributyl phosphate (TBP);
- electrical and electronic equipment:

- o Type 1: equipment with printed circuit boards (e.g. computers, telephones and stripped-down circuit boards);
- o Type 2: plant items (e.g. electrolytic capacitors and transformers);
- o Type 3: electrical and electronic tools (e.g. corded drills and cordless drills);
- o Type 4: mercury-containing items (e.g. fluorescent light tubes, vapour lamps and mercury switches); and
- o Type 5: rechargeable batteries (e.g. nickel-cadmium, nickel-metal hydride and lithium-ion).

We have included electrical and electronic equipment because:

- this equipment is present in large quantities in some waste streams and may account for the majority of waste in a consignment where a waste producer is decommissioning site plant;
- this equipment may contain Category 1 and Category 2 contaminants in small quantities and it would be onerous on waste consignors to calculate the quantities of these materials for each item of electrical and electronic equipment.

Consequently, we have developed a reporting mechanism using a means of classifying items of electrical and electronic equipment that contain Category 2 materials under Section L2.17 of the current WAC.

Consignors are required to provide the number of items of each electrical and electronic equipment type in a consignment. To convert this information into mass of Category 1 and Category 2 non-radiological contaminants, a 'material fingerprint' has been developed for each type. This approach is detailed in reference [133].

## **7.3 Controls Derived from Groundwater Assessment**

### **7.3.1 Approach to Calculating Capacities**

We have calculated non-radiological capacities as part of our groundwater assessment [134]. The assessment is structured against our Assessments Manual [109] and uses the same assessment model as we use to assess radiological impacts via the groundwater pathway.

The assessment model considers the full lifecycle of the repository, from first waste emplacement in the 1950s, through to disruption of the facility by coastal erosion and sea level rise. It therefore considers impacts that may occur both during the PoA and thereafter.

We have considered a range of assessment cases which explore the effects of different site evolutions and key uncertainties on assessed impacts, and which also allow the contribution of different barriers to the delivery of environmental safety to be elucidated. As with the radiological capacities discussed in Section 6, we consider that it is appropriate to set capacities based upon the reference case considered in the assessment.

We have calculated capacities for all contaminants listed in Subsection 7.2. Where materials, rather than contaminants are specified, we have used material fingerprints discussed in reference [134] and reference [133] to identify relevant contaminants for which to calculate capacities. For example, we take halogenated plastics to degrade to 1 ppm vinyl chloride and non-halogenated plastics to degrade to benzene.

Given updates to our understanding of the inventory, including assessing potential ILW disposal in the ESC, we have also undertaken a review to determine whether there are additional contaminants which should be included within the assessment [135]. We have calculated capacities for these additional non-radiological contaminants in reference [134].

We emphasise here that determination of a capacity for a contaminant does not imply that we have made a judgement that capacity management is warranted. Rather, we have determined capacities as a means of investigating the impacts arising from disposal of a given contaminant and to help inform views as to whether capacity management is proportionate.

We have determined capacities by calculating, for each non-radiological contaminant, concentrations in the groundwater at compliance points which are consistent with landfill guidance. When calculating capacities, we have had to consider the effects of solubility limitation, which may lead to situations in which assessed impacts do not increase linearly with the vault loading of contaminant. We have accounted for this by repeating the calculations for different vault loadings, with the non-radiological capacity being the mass of contaminant which could be disposed of in the vaults while ensuring that the peak impact from that contaminant would be equal to an appropriate assessment criterion. We therefore do not require prior knowledge of the vault inventory to calculate capacities.

In our assessment model, lateral flows may transport contaminants from the trenches to the vaults prior to release to the geosphere. To ensure that the solubility limits are correctly applied in the vaults, we have therefore included the trench inventory in our capacity calculations. Inclusion of the trench inventory also ensures that we have accounted for additivity of trench and vault impacts in the geosphere.

Calculated concentrations at compliance points may also (depending on the compliance point) include contributions from multiple vaults. We have addressed this additivity when calculating capacities by distributing contaminants between all the vaults. Given the additivity, we judge it appropriate to derive capacities which apply to the vaults as a whole, rather than derive capacities for individual vaults.

We have not accounted for wastes already disposed of in Vault 8 and Vault 9 when calculating capacities. This means that the calculated capacities apply to all vault wastes, rather than applying to the forward inventory only. The contribution of wastes disposed of in the vaults to capacity usage therefore needs to be considered when determining remaining capacity.

The assessment criteria we have used when calculating non-radiological capacities are as follows:

- For hazardous substances, we have taken the appropriate assessment criterion to be the most restrictive of the Environmental Quality Standard (EQS), the EU Drinking Water Directive (DWD) standard, the Minimum Reporting Value, and the limit of detection.
- For non-hazardous pollutants, we have taken the appropriate assessment criterion to be the most restrictive EQS for fresh or salt water or, where no EQS was available, the EU DWD standards have been used.

The assessment criteria we have used for each contaminant are provided in reference [134]. These have been taken to apply to all radioactive waste disposal at the site, including the summed impact of disposals to the trenches and vaults. There are no other disposals proposed at this time, for example of the 'site wastes' and contamination discussed in the *Waste Management Plan* [11].

### 7.3.2 Proposed Changes to Controls

Our HRA [16], along with calculated capacities [134], indicates that the impacts to groundwater from all contaminants currently managed as Category 1 contaminants will be very low. We consider it remains appropriate, therefore, for all these contaminants to remain assigned to Category 1.

In Table 7.1 we present calculated capacities for all contaminants currently in Category 2. In this table, we present results for benzo(a)pyrene (BAP). This is because we take BAP to be representative of polycyclic aromatic hydrocarbons in coal tar, which was used as a binder in pre-1980 tarmac and asphalt. It is therefore appropriate to consider the capacity for BAP when discussing controls on the acceptance of coal-tar-containing asphalt and tarmac.

For all contaminants except cyanide and selenium, calculated concentrations at the compliance points never exceed the relevant regulatory values. This means that, for these contaminants, there is no limit (from a groundwater perspective) to the quantity that could be disposed. Even for very large vault loadings, calculated impacts would remain lower than relevant assessment criteria.

**Table 7.1: Capacity limits for current Category 2 non-radiological contaminants [134]**

Pollutant	Maximum allowed mass loading in vaults (kg)
Arsenic	> 1 10 <sup>10</sup>
Benzo(a)pyrene (BAP)	No limit
Beryllium	No limit

Pollutant	Maximum allowed mass loading in vaults (kg)
Boron	No limit
Cadmium	No limit
Cyanide	3.8 10 <sup>5</sup>
Lead	No limit
Mercury	No limit
Selenium	1.1 10 <sup>7</sup>
TBP	No limit

Based on these results, we judge it appropriate to continue to manage disposals of cyanide and selenium against limiting capacities. We also consider it disproportionate to manage arsenic and contaminants with 'no limit' against limiting capacities and we therefore intend to re-categorise these contaminants as Category 1 contaminants. We emphasise that this does not imply that unlimited disposal of such materials represents BAT. There would still be a requirement for consignors to demonstrate that disposal at the LLWR would be the BAT approach.

There are additional considerations for mercury and BAP, which we discuss below.

### Mercury

While our view is that management against a capacity is not required for mercury, other controls in our WAC would limit the disposal of mercury-containing wastes. The prohibition on the disposal of free liquids limits the disposal of bulk quantities of mercury and therefore most mercury is consigned to the LLWR in relatively small quantities in electrical and electronic equipment. The use of fingerprints for electrical and electronic equipment would control our acceptance of most mercury-bearing wastes. We would strengthen this by explicitly stating in the WAC that:

- wastes may only contain trace quantities of mercury; and,
- requiring variations to be completed in support of any proposal to dispose greater than trace quantities of mercury.

### BAP, Asphalt and Tarmac

The main source of BAP in wastes disposed of at the LLWR is asphalt and tarmac. Our current WAC distinguish between pre- and post-1980 asphalt and tarmac (see Subsection 7.2).

Pre-1980 asphalt and tarmac are coal-tar-based. Coal tar contains polycyclic aromatic hydrocarbons (PAHs) such as BAP, and therefore pre-1980s asphalt and tarmac are

identified as Category 2 non-radiological contaminants and managed against a capacity limit.

Post-1980s asphalt and tarmac is bitumen-based, and the levels of PAHs present are typically several orders of magnitude lower than in coal-tar-based asphalt and tarmac [136]. Therefore, post-1980s asphalt and tarmac are identified as Category 1 non-radiological contaminants and not managed against a capacity limit.

We have reviewed technical guidance to the construction industry [137], which reports that:

- coal-tar-containing and bituminous asphalt and tarmac may be combined during construction or repair of a single section of road;
- coal tar and bitumen are miscible and contaminants can, therefore, migrate between them.

On this basis, we no longer consider it appropriate to distinguish between pre- and post-1980s asphalt and tarmac. It would be more appropriate to treat all asphalt and tarmac in the same manner in the WAC.

Tarmac and asphalt wastes with coal tar content of at least 0.1% by weight are hazardous wastes and must be disposed at an appropriately permitted disposal facility. Such disposal facilities would provide a lower level of environmental protection than the LLWR. The calculations reported in reference [134] provide evidence to support this statement: assessed impacts from BAP are sufficiently small that, as shown in Table 7.1, there is no limit, when considering impacts to groundwater, on the quantities of BAP that may be accepted for disposal.

As BAP is taken to be representative of all the PAHs that are found in coal tar, we therefore argue that it would be disproportionate to manage disposals of coal-tar-based asphalt and tarmac against a capacity limit. On this basis, we conclude that all asphalt and tarmac should be identified as Category 1 non-radiological contaminants.

### **Additional contaminants**

In reference [135] we identified that our assessment should include:

- bis(2-ethylhexyl) phthalate (DEHP), a plasticiser used in plastics;
- chromate (chromium(VI));
- formaldehyde;
- nitrate;
- styrene, which likely arises in wastes as an un-reacted monomer in polystyrenes, plastics or synthetic rubber.

We expect that nitrate will be microbially reduced to nitrite in the trenches and in the gaps between stacks of containers in the vaults. Subsequent reduction to ammonia, and then

dissolution to form ammonium is likely [6]. In our assessment and capacity calculations, we therefore model ammonium, rather than nitrate.

Calculated capacities for these contaminants are presented in Table 7.2.

**Table 7.2: Capacity limits for additional contaminants [134]**

Pollutant	Maximum allowed mass loading in vaults (kg)
DEHP	No limit
Chromium(VI)	No limit
Formaldehyde	$1.9 \cdot 10^5$
Ammonium	$> 1 \cdot 10^{10}$
Styrene	No limit

For all contaminants except formaldehyde, there is either no limiting capacity calculated or, in the case of nitrate, a very large limiting capacity is calculated. Capacity management is therefore not warranted for these contaminants.

We consider it appropriate to include chromate and nitrate as Category 1 contaminants. DEHP and styrene will be consigned to the repository in the form of plastics, polystyrenes and synthetic rubber. We currently record quantities of halogenated plastics and non-halogenated plastics which are disposed of at the LLWR. We propose to revise the WAC so that the quantities of polystyrenes and synthetic rubber disposed of at the repository are recorded.

The WAC prohibit the disposal of free liquids, which will prevent the consignment of bulk quantities of formaldehyde for disposal at the LLWR. Any formaldehyde in the wastes is therefore likely to derive from the microbially-mediated breakdown of cellulosic materials.

Microbial activity will be restricted under the high pH conditions in the grouted vault wastes, and therefore we do not expect large-scale generation of formaldehyde. Generation of formaldehyde is only likely to take place in isolated niches where lower pH conditions may be established. It is unlikely, therefore, that there will be substantial production of formaldehyde. Furthermore, formaldehyde is highly reactive and it is thus unlikely that, even if formaldehyde were to be produced in the vault near field, it would enter the geosphere from the repository. Our assessment cautiously neglects this and therefore likely overestimates releases to the geosphere.

Given these considerations, we judge that it would be disproportionate to control the disposal of formaldehyde precursors, as these are cellulosic materials which could, if not radioactively contaminated, be disposed of in landfills which would offer a significantly lower level of environmental protection than the LLWR. Our view is that the prohibition on the

disposal of free liquids provides sufficient control on the quantities of formaldehyde which may be disposed of at the LLWR.

In addition to these contaminants, we have also considered the disposal of silver and graphite, although our arguments regarding these contaminants are qualitative, rather than quantitative.

### **Silver**

We considered silver in reference [138] where we concluded, on the basis of assessment modelling, that management of silver disposals against a limiting capacity would be disproportionate.

We now consider, based on arguments presented in our *Engineering Performance Assessment* [13], that the cap will perform significantly better than when we undertook the assessment calculations reported in reference [138]. Using this revised understanding of cap performance, assessed impacts from silver would therefore be even lower than they were in reference [138]. We conclude, therefore, that it is appropriate to assign silver to Category 1.

### **Graphite**

Graphite is currently a Category 3 contaminant and has been disposed of to the LLWR previously under approved Waste Variations of WAC criterion L2.17 (*Hazardous Waste, Hazardous Substances and Non-hazardous Pollutants*). Previous consignments containing graphite included, for example, blow-down filters. We expect to receive applications to dispose of graphite which may include Advanced Gas-cooled Reactor (AGR) sleeve graphite.

We have considered the chemical and physical nature of graphite when assessing variations. Graphite is non-toxic, not water soluble and chemically inert under expected near-field conditions. The disposal of graphite will therefore have minimal impacts on groundwater.

Some forms of graphite, such as AGR sleeve graphite, have dust associated with them and a proportion of this may be of colloidal dimensions (approximately 1 µm or less). We expect, however, that the potential for such colloids to enhance contaminant transport will be limited. This is because of the following considerations.

- The low rates of water infiltration through the cap will limit colloid mobility.
- The waste containers will limit release of colloids.
- Colloids will, in general, be too large to diffuse through the grout pore space. Colloidal transport through the grout would therefore require advective flows through cracks in the grout. We do not expect that there will be flow of water through the grout matrix [6]. The grout in waste containers will therefore contribute to containing colloids.
- If colloids were to be transported from the wastes, we expect that colloids will be filtered by natural sediments [15].

Sorbed gases (predominantly carbon dioxide or carbon monoxide) may be lost from graphite slowly over time. However, the rate of release of these gases is very low and highly unlikely to have a chemotoxic impact.

Given all these considerations, we judge it appropriate to treat graphite as a Category 1 contaminant.

### **7.3.3 Summary of Proposed Changes**

In summary, based on our groundwater assessment, we propose the following changes to the WAC:

- electronic and electrical equipment will remain as Category 2 contaminants;
- arsenic, beryllium, boron, cadmium, graphite, silver and TBP will be categorised as Category 1 contaminants;
- we will no longer distinguish between pre-1980 and post-1980 tarmac and asphalt, and we will assign tarmac and asphalt to Category 1;
- mercury will be re-categorised as a Category 1 contaminant, and we will revise the WAC to:
  - state that wastes may only contain trace quantities of mercury; and,
  - require variations to be completed in support of any proposal to dispose greater than trace quantities of mercury;'
- include chromate and nitrate as Category 1 contaminants;
- assign polystyrenes and rubber to Category 1;
- while cyanide and selenium will continue to be managed as Category 2 contaminants, we will manage them against the capacities reported in Table 7.1.

The proposed updates to the WAC will not apply immediately and will be subject to consultation with the Environment Agency and relevant notifications under condition 4.3 of the Permit. This could include further guidance on how BAT should be applied when considering disposal of non-radiological contaminants.

## **7.4 Asbestos**

Environment Agency guidance for disposal of non-radioactive asbestos waste [129] focuses on preventing the waste being disturbed and preventing asbestos dust being generated. We take the following measures to minimise the potential for generation of asbestos dust during the Period of Authorisation:

- we require all asbestos to be packaged in accordance with HSE requirements for handling and transport so as to ensure that dust is not generated while accepting and handling the waste;
- our WAC [71] require that asbestos is either supercompacted or double bagged;

- asbestos accepted for disposal at the LLWR would usually be grouted into a container, in accordance with our WAC for waste packaging.

Since the LLWR is a radioactive waste disposal facility, we operate controls during the PoA to prevent the disturbance of all waste in the facility (including asbestos-containing waste).

We have also considered the post-closure safety risks to members of the public from exposure to disposed asbestos following inadvertent human intrusion and coastal erosion.

This study [139]:

- quantified the potential amounts, types and form of asbestos requiring future disposal in the repository;
- assessed the performance and cost of viable asbestos treatment and conditioning techniques;
- quantified the risks associated with disposal of untreated asbestos in the repository and evaluated the effect on these risks of applying viable treatment and conditioning techniques.

The conclusions of this study informed our current WAC limits on the mass of asbestos permitted in a consignment [140]. The principle behind the WAC limits is that the risks of asbestos exposure arise from inhalation of airborne asbestos fibres and the potential for release of airborne fibres depends on the friability of the material [140]. Our WAC limits, therefore, depend on the friability of the asbestos [71] as follows.

- Non-friable and low friability asbestos-containing material has no or very low potential to release airborne fibres and we do not apply a limit.
- Moderately friable asbestos-containing material has some potential to release airborne asbestos fibres and we limit this to one tonne of the material per consignment.
- Highly friable asbestos-containing material has high potential to release airborne asbestos fibres and is likely to have a much higher asbestos content than the less friable materials, and we limit this to 10 kg per consignment.

Disposal of asbestos-containing material above these limits requires a variation. For any disposals assessed under the variation process, we would collect more details about the material, the associated risks and any treatment proposed or done to reduce the friability of the material.

We recently reviewed the assessment in reference [139]. We considered whether scientific, regulatory or technological developments or changes to the LLWR ESC and plans for the site would require us to revise our WAC for asbestos. We concluded that no changes to our WAC were required [141].

## 7.5 Flammable and Chemotoxic Gases

The most important chemotoxic gases are hydrogen sulphide and ammonia, which are likely to be generated under the anaerobic conditions present in the trenches and also in the vaults where microbial activity can occur. We considered these gases in reference [6], where we noted that these gases are highly soluble and reactive, and therefore it is unlikely that significant volumes will be released in a gas phase. Results from our monitoring programme indicate that gaseous hydrogen sulphide and ammonia are not present in significant volumes nor are they likely to be present in significant volumes in the future [9].

We have also considered the impacts of trace chemotoxic gases. As reported in reference [6], the impacts are insignificant [142]. Given these considerations, we do not consider it necessary to put in place waste acceptance measures to limit the generation of chemotoxic gases.

The most significant flammable gases are methane and hydrogen. We have considered the generation of methane in reference [6], where we concluded that, in the grout-conditioned porewater in the vault wastes, microbial activity will be strongly restricted so that the generation of methane from organic materials will be limited and may not occur at all. We also generally expect that methane released through the cap will be oxidised in the soil layer to CO<sub>2</sub> by soil microbes. We do not therefore consider it necessary to establish controls on the inventory to reduce the generation of methane gas.

The main flammable gas of interest is hydrogen. We have examined, as part of our radon assessment, the quantities of hydrogen gas which could enter a house built on the open vent on the cap. Cautious calculations suggest that levels of less than 0.2% hydrogen could occur, compared with the 4% hydrogen usually taken as the lower explosive or flammable limit for hydrogen in air at 25 °C [106]. We do not consider it likely, therefore, that impacts from hydrogen would be significant.

## 8 Waste Acceptance Arrangements

This section describes our plans for the implementation of the necessary controls on waste acceptance identified in the previous sections. Implementation of our waste acceptance arrangements is achieved through:

- The overall waste acceptance process;
- Revisions to the WAC issued to waste consignors;
- An emplacement strategy within the disposal vaults to manage specific waste streams and waste consignments.

Necessary changes will be brought into operation in a planned and phased manner, with priority given to those aspects that if not enacted would have negative environmental safety implications. Nevertheless, it is important that all updates are implemented as soon as practicable. Timely adoption of these updates ensures that waste continues to be managed in line with best practice and optimisation principles, avoiding consignors deciding not to propose to send wastes to the LLWR where it would be the optimal management approach. A programme of work is being established for this and will be discussed with the Environment Agency and other stakeholders. Important considerations in terms of implementation are listed below.

- The need to ensure an integrated and proportionate approach throughout the waste acceptance process.
- The need to ensure alignment with the findings and assumptions of the ESC in terms of waste acceptance and compliance with the Permit for the site, to ensure it is operated in accordance with BAT [23].
- The need to develop specific revisions to the WAC and for these to be brought into operation by consignors.

The Permit for the site places several requirements on the types and quantities of waste that can be accepted for disposal. These include sum of fractions based limits on the radionuclide content of the wastes and restrictions on the nature of the wastes, in particular materials that must be excluded. We will ensure that any changes to our waste acceptance arrangements will maintain compliance with the Permit.

In terms of WAC, these are updated from time to time for several reasons, for example developments in acceptance arrangements and in waste management practices. Any changes to the WAC need to follow formal procedures [58], in which an LLWR WAC Interpretive Authority holds overall responsibility, and which may involve review of the proposed criteria by internal stakeholders. It also includes formal consultation with consignors to ensure they can be practicably implemented and to enable the efficient introduction of the required changes. All revisions to the WAC will continue to be issued to

the Environment Agency prior to their introduction and would be subject to relevant notifications under condition 4.3 of the Permit.

The requirements of the ESC in terms of waste acceptance, identified in Sections 3 to 7, are summarised in Table 8.1. Many aspects will remain unchanged by the work done to support the 2026 ESC. However, as identified above, implementation of changes will be achieved through modifications to the WAC, whilst others will require changes to the waste acceptance process or emplacement strategy. These aspects are discussed further in the following subsections.

**Table 8.1: Summary of requirements identified from the ESC**

ESC Requirement (with report Section for further details)	Means of Implementation		
	Waste Acceptance Process	WAC	Emplacement Strategy
Waste containers (§4.1)	✓	✓	✓
Grouted waste form (§4.2)	✓		
Retention of absorbed liquids (§4.3.1)		✓	✓
Treatment of soluble salts and ion exchange materials (§4.3.2)		✓	
Treatment of powders (§4.3.3)		✓	
Control of inaccessible voidage and biodegradable materials (§4.4)	✓	✓	✓
Restrictions on complexing agents (§5.1)		✓	
Controls on total vault activity (§6.3)	✓		
Controls on consignment activity (§6.4)	✓	✓	✓
Controls on sub-container scale activity (§6.5)		✓	✓
Fissile controls (§6.6)		✓	
Controls on non-radiological content of waste (§7)		✓	

## **8.1 Waste Acceptance Controls**

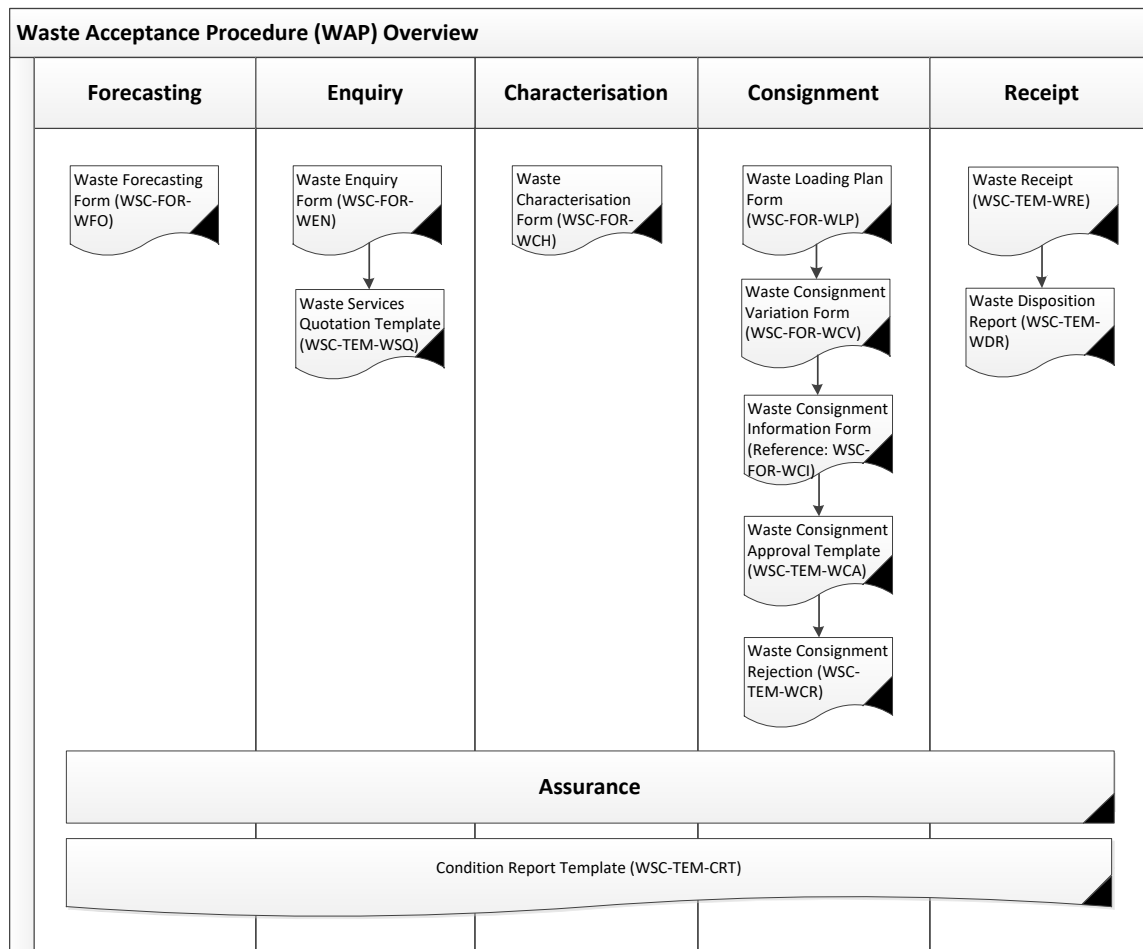
### **8.1.1 Current Waste Acceptance Procedure**

The waste acceptance procedure (WAP) overview document [143] provides a summary of the waste acceptance procedure. It gives consignors key information about the services available for waste characterisation, transport, treatment and disposal, and acts as an introduction to the process and requirements for consigning waste to the LLWR. This includes the consigning of LLW for disposal at the LLWR and also the other waste management services that we offer to customers. The WAP is the set of protocols and steps that ensure only permitted and suitable waste (i.e. waste which meets the WAC) is accepted at the disposal facility.

To consign waste to the LLWR for disposal, there are several prerequisites that must be in place. Consignors must hold an authorisation such as a permit issued under the Environmental Permitting (England & Wales) Regulations 2016 (as amended). Consignors must also hold a waste services contract and in certain circumstances may require an agreement in principle to dispose. In some cases, transfrontier shipment authorisations and third-party waste agreements must also be in place.

Once all relevant prerequisites are in place customers should follow the WAP. The WAP includes the following elements: waste forecasting, waste enquiry, waste characterisation, waste consignment, waste receipt and waste assurance (see Figure 8.1). Process diagrams, training, guides, forms and templates to facilitate understanding and aid implementation of the process, accompany these. These elements of the waste acceptance procedure are summarised below.

**Figure 8.1: WAP overview**



**Waste forecasting** is the stage of the acceptance process that requires customers to provide a 12-month forecast (as a minimum) (updated every six months) of their waste treatment and disposal requirements in terms of volume, radioactivity content and container supply requirements.

**Waste enquiry** is the starting point for consigning a specific volume of waste to the LLWR. It is designed to promote early engagement between us and customers to develop treatment and disposal plans for particular waste types and volumes. The appropriate form requires details of waste description, waste composition, physical properties, radiological properties and waste packaging options. It relates to a particular quantity of waste such as a single consignment of waste, a multi-year operational waste stream or an entire decommissioning project. It is also the process by which a waste services quotation is provided to the customer that includes the service information, including any necessary variations that would be required to meet the WAC.

**Waste characterisation** is the process that requires customers to detail the techniques they have used to characterise their waste. We use the information provided to confirm that the characterisation techniques will result in an accurate declaration of the radioactivity content of the waste during the waste consignment process. The waste characterisation process must be completed and approved before a customer can consign waste. In reviewing

approaches to waste characterisation, we consider the robustness of the characterisation, relevance to the selected treatment and/or disposal option, radioactivity content trigger levels and the suitability of activity assessment methods. Activity 'trigger levels' identify those waste streams that would take up a significant amount of the disposal limits specified in the Permit. Such wastes are only accepted after full assessment that disposal at the LLWR is the optimum waste management option for that waste stream, adequate radiological capacity is available and that its disposal is consistent with the UK Strategy for LLW management [144]. Following review of the characterisation, we issue an activity allocation of capacity to the customer for the given waste stream.

**Waste consignment** process considers the acceptance of each waste consignment. A Waste Consignment Information Form is completed to provide detailed information on the contents of a specific container of waste. This process includes a range of checks carried out by NWS to confirm that all appropriate requirements have been met and that the wastes are acceptable for disposal. If it has been necessary to obtain approval for a variation to the WAC, the consignor must submit details and obtain agreement using a Waste Consignment Variation Form (see Section 8.3).

**Waste receipt** is the last process to be followed in consigning a single container of waste. This process includes the waste receipt checks and waste assurance monitoring to provide confirmation that the consignment complies with the relevant WAC, the waste services quotation and the Waste Consignment Information Form. The process is complete once NWS issues a waste disposition report, detailing the final status of the consignment when the treatment and/or disposal services are completed. The information provided forms the lifetime record of waste disposed of at the LLWR.

**Waste assurance** requires customers to provide re-assurance to NWS that their own waste management arrangements and procedures will ensure that waste consigned for treatment and/or disposal will comply with the requirements of both the WAP and the WAC. This is an ongoing, risk-based process between the Customer and NWS for the duration of the Waste Services Contract. The process also includes the activities that we undertake to provide assurance that waste consigned is as described in the waste consignment form. These objectives are achieved by undertaking customer audits and independent assurance monitoring of waste consignments. It is noted that the Environment Agency, through its Waste Quality Checking, may also carry out its own independent checking of LLW consigned to the LLWR. The overview WAP includes the necessary details for delivery of wastes and communication routes between customers and NWS, details of record keeping requirements and a glossary of defined terms used within the process. The WAP is managed within NWS as part of its integrated management system that ensures quality throughout the application of its processes for managing the acceptance and emplacement of wastes. This includes important aspects such as documented procedures, training of personnel, waste tracking systems and record keeping.

We also implement continuous improvement projects relating to implementation of the ESC. In 2018 a Waste Misconsignment Risk Mitigation Project was initiated in response to a

number of significant misconsignments to the LLWR [145]. This project has driven improvements by delivering on ten recommendations that address the definition and understanding of the WAC, improvements to WAP and associated management arrangements, training, assurance methods and stakeholder engagement. The number of misconsignments to LLWR since initiation of the improvement project has reduced.

## 8.1.2 Managing against Capacities and Limits

### 8.1.2.1 Vault Capacities

A fundamental requirement that has been identified is that, to ensure environmental safety, the total inventory of the vaults should be controlled through the set of limits given in Subsection 6.3.4.

LLWR currently has maximum capacities for:

- radionuclides;
- specific complexants;
- specific non-radiological substances.

Currently, radionuclide disposals are controlled consistent with the set of sum-of-fractions limits for individual radionuclides or groups of radionuclides for five assessment cases of the 2011 ESC stipulated in the Permit. eMWaste is the waste tracking system software used to manage both future capacity and inventory data for waste consigned to and disposed of at the LLWR [146].

Planning and control of the total inventory capacity is currently carried out as part of the waste stream characterisation stage. This is then supported by controls at the waste consignment stage in terms of checking of consignment data and at the waste receipt stage in terms of final recording of information. Following review of the characterisation, we issue an activity allocation of capacity to the customer for the given waste stream through approval of a Waste Characterisation form (WCH). A decision to issue an activity allocation includes the following considerations in relation to capacity management:

- **UKRWI inclusion.** Whether or not the waste stream was included in the latest iteration of the UKRWI. If it has, capacity is typically favoured, because it means the waste stream was included in the ESC assessment calculations.
- **Permit notification requirements.** Currently the Compilation of Environment Agency Requirements, Approvals and Specifications (CEAR) to the Permit requires us to notify the Environment Agency if the sum of fractions of any of the five assessment cases increases in a financial year by more than 0.01, and if the contribution to the sum of fractions of any of the five assessment cases is greater than 0.005 from a Waste Characterisation Form for a waste stream approved for disposal. We have internal controls to ensure these requirements are fulfilled.
- **Management decision levels for capacity usage.** Thus far, decisions on acceptance of waste at the LLWR have involved allocation of very small fractions of

the total or remaining capacities. It is expected, however, that requests will be made to dispose of wastes that would use large fractions of at least some of the different capacities, implying decisions of a strategic nature and large cost implications. Therefore we have defined an escalation process for decisions, so that they are made at an appropriate management level, up to the Nuclear Decommissioning Authority's Senior Strategy Committee (NDA's SSC) for NWS [147]. These decision levels are not about the safe management of the facility, provided the capacities are not exceeded, but about best use of the NDA's LLWR asset.

- **Decision levels for proportionate capacity usage.** Based on the amount of radiological capacity used by a waste stream in relation to its volume, this control helps inform whether disposal at the LLWR represents BAT and would support emplacement decision-making, particularly if ILW were to be accepted. The proposed decision levels are shown in Table 8.2. This is a new measure that we propose to introduce as part of implementing the 2026 ESC. The capacity usage index (CUI) is defined as the fraction of radiological capacity usage divided by the fraction of vault airspace used for each waste stream, meaning that a CUI of 1 reflects uniform homogenous use of the total vault capacity.

**Table 8.2: Decision levels for capacity usage and escalation**

	<b>Radiological Capacity*</b>	<b>Non-radiological Capacity*</b>	<b>EDTA-type Complexants*</b>	<b>Physical Volume (m<sup>3</sup>)</b>	<b>Responsible Individual for Escalation</b>
Waste Compliance team	<0.0005	<0.0005	<0.0005	<125	Waste Compliance Manager
Head of Safety Cases	<0.005	<0.005	<0.005	<1,250	Head of Safety Cases
SWMC	<0.01	<0.01	<0.01	<2,500	SWMC Chair
NWS Board	>0.01	>0.01	>0.01	>2,500	NWS Board Chair
NDA SSC	>0.01	>0.01	>0.01	>2,500	

\* The figures are fractions of remaining capacity, with the exception of physical volume

**Table 8.3: Proposed decision levels for proportionate capacity usage**

	<b>Capacity Usage Index (CUI)</b>	<b>Note</b>	<b>Responsible Individual for Escalation</b>
Waste Compliance Team	<10		Waste Compliance Manager
SWMC	<50	Consignor is contacted and requested that their BAT case for the management of the waste should take account of the CUI, in collaboration with NWS.	SWMC Chair
NDA SSC	>50	Consignor is contacted and requested that their BAT case for the management of the waste should take account of the CUI, in collaboration with NWS.	

Decisions on the Best Available Technique (BAT) for waste management must consider optimal use of LLWR capacity.

If we were to accept ILW at the LLWR, there would be more ILW available for disposal than can be accommodated by the radiological capacity. We would therefore develop a plan for allocating disposal capacity. This is because prioritising waste on a ‘first-come, first-served’ basis does not guarantee best use of available space, though timing may influence decisions. This plan would outline expected waste disposals over LLWR’s lifetime. Waste will be accepted according to the plan, provided it meets the Waste Acceptance Criteria (WAC) or an agreed variation. We would create this plan in collaboration with the NDA and waste consignors, providing consignors with certainty for decommissioning and waste management plans. This approach will also help us and the NDA plan for further disposal capacity, including the Geological Disposal Facility (GDF) and potential new near-surface facilities.

Stakeholders must agree on which wastes to prioritise and the importance of each factor. Factors may include the following.

- Enabling hazard reduction by prioritising wastes from certain decommissioning projects.
- Cost savings achieved by disposal.
- Timing, as prioritising early waste before alternative disposal facilities open may lower impacts from storage. Government policy also favours early solutions.
- Physical volume, since surface disposal at LLWR is cheaper per unit volume. Prioritising larger volumes may reduce costs, favouring disposal of Low Level Waste (LLW) over Intermediate Level Waste (ILW). However, the NDA does not currently plan to dispose of large Very Low Level Waste (VLLW) volumes at LLWR.
- Use of radiological capacity in relation to volume (i.e. the capacity usage index [CUI])

The goal would be to use LLWR optimally in line with new policy. NDA strategy work on near-surface disposal of ILW has created example inventories based on cost-benefit analysis and discussions with waste producers; these can inform LLWR capacity planning.

The United Kingdom Radioactive Waste Inventory (UKRWI) will play a key role in shaping capacity plans. Uncertainties exist in operational and decommissioning plans and waste arisings, but the new policy requires ongoing optimisation of LLWR use. The plan would be reviewed and updated as new information emerges, possibly more often than the UKRWI's current three-year cycle, to ensure safety, environmental, or financial benefits are realised.

Currently, we allocate repository capacity to waste producers as part of approving characterisation of a waste stream through the waste characterisation process. If the waste stream appears in the UKRWI, capacity is typically granted. The proposed capacity allocation plan will replace the UKRWI's role in the acceptance process.

#### **8.1.2.2 Consignment Limits**

Controls against consignment limits are undertaken at the waste consignment stage within the acceptance process. The review of Waste Consignment Information Form (WSC-FOR-WCI) is used to identify consignments that require management as part of emplacement strategies.

In terms of the consignment activity limits, the sum of fractions identified in Subsection 6.4.3 will be applied.

Firstly, consignments that exceed the sum of fractions using the radiological capacity values in Table 6.9 are identified as part of the overall approval process against the criteria given in Subsection 6.4.1.

Secondly, consignments that exceed the sum of fractions in **Table 6.12** are identified to ensure that the objectives of the emplacement strategy for excluding such wastes from the top and bottom stack positions can be successfully implemented.

Consignments potentially requiring such control are identified based on evaluation of the sum of fraction using radionuclide data given on each WCI form and the ungrouted weight of each consignment. The results of this provisional assessment are recorded on the WCI.

Consignments that require emplacement in line with the Ra-226 controls of Subsection 6.4.1.3 will be identified.

As is current practice, any consignments for which emplacement restrictions apply, for example Total Potential Voidage (TPV), are identified. A list of all such consignments is provided to the site operations team, prior to consignment delivery, along with the measures to be taken for each clearly identified.

For consignments identified as potentially requiring emplacement at lower levels of the stacks, the operations team will provide the grouted weight of the consignment and a final sum-of-fraction value will be generated based on the provisional sum-of-fraction value multiplied by the ratio of ungrouted to grouted weight. For those consignments with final sum-of-fraction values greater than 1, the operations team will need to select emplacement positions ensuring that any stack has no more than one such consignment and that consignments are in appropriate stack levels.

One of the requirements of the ESC is that wastes that include absorbed liquids must have applied loads not exceeding  $400 \text{ kN m}^{-2}$  from the overlying wastes and final cap. This is controlled on the basis that, for standard containers, no further controls are necessary provided that the weight limits are complied with (Subsection 4.3.1). Control against this aspect will be achieved by a combination of the waste consignment stage in which non-standard consignments are identified together with additional operational controls at waste emplacement to confirm that total stack masses are within acceptable limits. This latter aspect is part of the waste receipt stage of the waste acceptance process that includes the waste disposition report.

### **8.1.2.3 Sub-Container Scale Limits**

Sub-container activity heterogeneity is currently assessed in line with L3.2.3 of the WAC. We recognise that this criterion leaves room for interpretation, which can cause challenges for consignors and ourselves when comparing consignments against the criterion. As such, we have undertaken work to provide a numerical basis to the criterion derived from considerations of environmental safety.

Potential numerical controls are outlined in Section 6.5 and require consultation with the Environment Agency and consignors. This will include consideration of how any numerical controls would be practically implemented.

Discrete item limits are defined in the WAC. We provide guidance on what constitutes a discrete item through an online database resource [148]. The WCI requires consignors to itemise discrete items on a register, provide a photograph and declare activity information at the item level to demonstrate compliance with the sum-of-fractions limit for the individual discrete item and all discrete items collectively in the container.

The WAC provides definitions for the size, nature and typical activity threshold of what constitutes an active particle, with direction that waste containing active particles may be accepted for disposal but only on approval of a WCV.

For low-activity sources, where justified that these cannot be returned to the supplier, manufacturer or other alternative use, numerical limits and packing requirements are defined in the WAC. Low-activity sources are required to have a separate WCH and the WCI requires consignors to itemise the information on a register.

For these controls, there is also further guidance available to consignors through the WAC Explained (WAC-X) online resource available through the NDA Connect platform.

#### **8.1.2.4 Reporting and Review Arrangements**

In addition to the reviews detailed in Subsection 3.4, there will be changes necessary to the documentation associated with the controls on wastes and to the associated support systems as a result of the 2026 ESC. There will also be changes required to management arrangements and necessary training of personnel. The introduction of these measures will entail changes both by ourselves and by consignors. We will consult with the Environment Agency and with our customers to ensure the efficient introduction of the necessary changes as soon as reasonably practicable and to ensure the requirements of the ESC are met.

## **8.2 Waste Acceptance Criteria**

This subsection describes how those WAC that derive from the ESC can be incorporated into the overall WAC that define wastes acceptable for disposals at the LLWR. The issues to be addressed are identified in Table 8.1 and the underlying basis for these have been identified in Sections 3 to 7. A revised WAC will be generated as part of the programme of ESC implementation.

The current WAC for disposals of LLW to the LLWR [71] are presented in following three parts.

- 1) **Physical and chemical properties.** This includes aspects of waste segregation and treatment, that only solid radioactively contaminated or activated waste is accepted for disposal and the requirements for materials that must be excluded or only present in limited quantities.
- 2) **Radiological properties.** This includes radioactivity limits, fissile controls and radiation and contamination criteria.
- 3) **Packaging and transport requirements.** These define requirements for waste containment, voidage limitation and waste packing.

The current WAC together with the changes or additions required for implementation of the findings of the 2026 ESC are given in Table 8.4. It includes our conclusions as to whether the requirement is retained as is or should be amended. In each case the purpose of the

WAC is briefly summarised and, for ESC-related aspects, a cross-reference is given to the relevant section of this report.

There are other planned upcoming changes to the WAC that are not driven by the 2026 ESC. Examples of these include changes to WAC relating to consignor BAT requirements, based on previous correspondence with the Environment Agency. We also propose to introduce explicit requirements for safeguarded materials. There are also cases where interpretation of the current WAC has been clarified to consignors through customer notices or through the NDA Connect online platform WAC-X resource. An example of this is where it was clarified through customer notice LLWR-CN-2021-010 and WAC-X that the purpose of the 10kg limit on friable asbestos was to enable disposal of Personal Protective Equipment contaminated with highly friable asbestos or similar wastes, but not for disposal of 10kg of or bulk volumes of high friable asbestos. Where appropriate these clarifications and interpretations will be incorporated into the updated WAC.

Any change to the WAC would need to follow formal procedures [58], in which an LLWR WAC Interpretive Authority holds overall responsibility, and which may involve review of the proposed criteria by internal stakeholders and a formal consultation exercise with consignors to ensure they can be practicably implemented and to enable the efficient introduction of the required changes. As required by the Permit, we will consult with and notify the Environment Agency on revisions to the WAC prior to their introduction.

We have highlighted the changes to the WAC that may be required as a result of the updated ESC in Table 8.4.

**Table 8.4: Current WAC and basis for expected revisions<sup>28</sup>.**

Paragraph	Current WAC	Our Conclusions
L1 General Conditions of Acceptance	<p>Waste will only be accepted for disposal at the Low Level Waste Repository if this management route is Best Available Techniques (the term Best Available Techniques is used throughout the document but is intended to encompass Best Practicable Environmental Option and Best Practicable Means where applicable). Customers shall ensure that Best Available Techniques have been adopted to segregate the constituent parts of wastes such that alternative waste treatment and / or disposal services can be used to avoid disposal at the Low Level Waste Repository. Where waste is not selected for alternative management route, acceptance will require Suitable Supporting Justification to be provided; this should be for the Wastestream or Waste Consignment as appropriate.</p> <p>Waste will only be accepted at Low Level Waste Repository if it meets all the conditions and criteria specified in this document or an approved variation is in place.</p> <p>Waste will only be accepted from customers in accordance with NWS's Waste Acceptance Procedure.</p> <p>Waste will only be accepted for disposal at the Low Level Waste Repository providing sufficient Volumetric, Radiological and Non-radiological Capacity has been allocated.</p> <p>Capacity is managed by NWS based in part on information in the UK Radioactive Waste Inventory; wastes will therefore only be accepted if identified as Low Level Waste in the latest issue of the UK Radioactive Waste Inventory or after an assessment against remaining capacity by NWS.</p>	No changes proposed.

<sup>28</sup> Terms in italics are defined in the associated glossary [71]

Paragraph	Current WAC	Our Conclusions
<b>L2 Physical and Chemical Properties</b>		
L2.1 Waste Volume	Customers shall ensure that Best Available Techniques have been adopted to reduce the Package Volume requiring disposal at the Low Level Waste Repository.	No changes proposed.
L2.2 Acceptable Waste	<p>Only solid radioactively contaminated or activated waste will be accepted for disposal at the LLWR.</p> <p>Waste Consigned for disposal must be compliant with the Permit issued under the Environmental Permitting (England and Wales) Regulations 2016 by the Environment Agency (Reference: EPR/YP3293SA). Compliance with the Permit can be achieved by complying with the requirements of these WAC and consigning waste in accordance with the WAP.</p>	No changes proposed.
L2.3 Waste Preparation	Waste must have been treated or packaged in such a way as to render it, so far as is reasonably practicable, insoluble in water and not readily flammable.	No changes proposed.
L2.4 Non-Waste Materials	Where materials must be added to the waste, the customer shall use reasonably practicable means to limit the quantity of non-waste materials present in a Waste Consignment. It is not acceptable to purposely dilute waste or add materials for shielding purposes or otherwise for the sole purpose of achieving compliance with the requirements of this Waste Acceptance Criteria.	No changes proposed.
L2.5 Reactive Metals and Materials	Customers shall use Best Available Techniques, which might be by painting or wrapping, to limit the surface area of Reactive Metals accessible by grout. In any case, the total exposed (including any wrapped metal but not painted) surface area of Reactive Metal must not exceed 10 m <sup>2</sup> .	Ongoing Nuclear Safety Case (NSC) work relating to hydrogen generation during grouting may result in an

Paragraph	Current WAC	Our Conclusions
	Other materials that readily react either with each other, grout, water or air, with the evolution of heat or flammable gases, or in a way that might affect containment of the wastes, may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FORWCV) with Suitable Supporting Justification by NWS.	update to the pre-treatment requirements and allowable quantity of exposed surface area to ensure BAT and ALARP for controlling the risk of a hydrogen explosion hazard at the LLWR site.
L2.6 Explosive Materials	Waste shall not contain Explosive materials or materials that readily react with air, water or grout to cause an Explosive hazard.	No changes proposed.
L2.7 Liquids	<p>Waste shall not contain any Free Liquid or liquids with flashpoint less than 21 °C absorbed on solid materials.</p> <p>Aqueous and / or non-aqueous liquid waste may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification by NWS. In addition, the following conditions must be met:</p> <ul style="list-style-type: none"> <li>• Any liquid shall, prior to Consignment, be fixed in a Suitable Solid Matrix which will not result in release of liquid under applied loads of up to 400 kN m<sup>-2</sup>;</li> <li>• The non-aqueous content of any liquid in the waste shall be conditioned, prior to Consignment, such that no visible oil or grease will be released by leaching as demonstrated using a Leach Test agreed with NWS.</li> </ul>	No changes proposed.
L2.8 Soluble Solids	Soluble Solids present as Bulk Chemical Compounds greater than 1 kg mass in a Waste Consignment may be accepted for disposal but only on approval of a Waste Consignment	No changes proposed.

Paragraph	Current WAC	Our Conclusions
	Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification by NWS. Such materials shall be fixed, prior to Consignment, in a Suitable Solid Matrix that will not readily release that component as demonstrated using a Leach Test agreed with NWS.	
L2.9 Strong Oxidising Agents	Waste shall not contain strong oxidising agents.	No changes proposed.
L2.10 Corrosive Materials	Waste shall not contain any material such that the expected performance and integrity of the Disposal Container could be significantly reduced, unless such materials are treated, prepared or made safe by a method approved in advance by NWS.	No changes proposed.
L2.11 Pressurised Gas Receptacles and Aerosols	Waste shall not contain pressurised gas receptacles and aerosols, as defined within The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (or as amended). Such items that have been depressurised are acceptable for disposal.	No changes proposed.
L2.12 Toxic Materials	Waste shall not contain materials that, in contact with air, water, grout or otherwise, generate or are capable of generating, toxic liquids, gases, vapours or fumes harmful to persons.	No changes proposed.
L2.13 Chemical Complexing or	To fulfil regulatory requirements in relation to disposals at the Low Level Waste Repository, radioactive waste containing Chemical Complexing and Chelating Agents must be controlled. Such wastes are managed using the following categories:	No changes proposed.

Paragraph	Current WAC	Our Conclusions
Chelating Agents	<p>Category 1: Materials requiring control but not requiring an allocation; the quantities of the materials must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI). These materials are:</p> <ul style="list-style-type: none"> <li>• Carboxylic acids: examples include citrate, picolinate, oxalate and formate;</li> <li>• Inorganic compounds: for example tri-polyphosphates.</li> </ul> <p>Category 1 materials will only be permitted in quantities less than Bulk Chemical Compound quantities in waste.</p> <p>Category 2: Materials requiring an allocation. These may be accepted for disposal subject to there being sufficient capacity for these materials at the Low Level Waste Repository. This will be assessed based on information in Waste Characterisation documents (Reference WSC-FORWCH) and in the UK Radioactive Waste Inventory. In cases for which there is not sufficient capacity, or in which the usage of the capacity would be grossly disproportionate to the volume of waste, this will be discussed with customers including the potential need for additional information. Customers shall ensure that the total disposal of such materials for each Wastestream does not exceed the allocation given by NWS. These materials are:</p> <ul style="list-style-type: none"> <li>• EDTA (ethylene-diamine tetra-acetic acid and salts thereof);</li> <li>• DTPA (diethylene-triamine penta-acetic acid and salts thereof);</li> <li>• NTA (nitrilo-acetic acid and salts thereof).</li> </ul> <p>Customers shall ensure that Best Available Techniques have been adopted in the management of wastes to minimise the quantity of Chemical Complexing and Chelating Agents, described in Category 1 and Category 2 above, requiring disposal at the Low Level Waste Repository.</p>	

Paragraph	Current WAC	Our Conclusions
	<p>Some materials, which may be complexing by virtue of their chemical mode of action, are specifically excluded from control as Chemical Complexing and Chelating Agents. These materials are:</p> <ul style="list-style-type: none"> <li>• Ion-exchange materials;</li> <li>• Superplasticisers (as a component of cured cement, concrete or grout);</li> <li>• Coagulants and flocculants;</li> <li>• Low molecular weight ions that are commonly occurring or ubiquitous in the natural environment (e.g. ammonium ions).</li> </ul> <p>Other proprietary chemicals and reagents containing Chemical Complexing and Chelating Agents not listed may be accepted for disposal but only on approval by NWS of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and Suitable Supporting Justification. Such materials may need to be fixed, prior to Consignment, in a Suitable Solid Matrix that will not readily release that component as demonstrated using a Leach Test agreed with NWS.</p>	
L2.14 Ion Exchange Materials	Waste shall not contain Ion Exchange Material unless conditioned using a method approved in advance by NWS. This is likely to involve the Ion Exchange Material being fixed, prior to Consignment, in a Suitable Solid Matrix approved in advance by NWS.	No changes proposed.
L2.15 Biological, Infectious and	Waste shall not contain biological, pathogenic or infectious materials, as listed within Hazard Groups 2, 3 or 4 in the Approved List of biological agents produced by The Advisory Committee	No changes proposed.

Paragraph	Current WAC	Our Conclusions
Pathogenic Materials	<p>on Dangerous Pathogens, unless treated such that no viable micro-organism(s) from Hazard Groups 2, 3 or 4 exist by a method approved in advance by NWS.</p> <p>Customers shall use reasonably practicable means to limit the quantity of Putrescible Materials within a Waste Consignment and if present Putrescible Materials must not exceed 1% of the Internal Volume of the Disposal Container. Amounts exceeding this may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification by NWS. The supporting justification must include:</p> <ul style="list-style-type: none"> <li>• A Best Available Techniques assessment of potential treatment options;</li> <li>• An assessment to consider potential human health implications.</li> </ul>	
L2.16 Waste Degradation, Voidage and Settlement Properties	<p>It is important to control Total Potential Voidage in wastes to limit the settlement of wastes and hence the final cap of the Low Level Waste Repository. Total Potential Voidage is the sum of Inaccessible Voidage, Compression Voidage and Biodegradation Voidage.</p> <p>Customers shall use Best Available Techniques in order that wastes are treated so as to minimise the Total Potential Voidage in each Waste Consignment and in any case the Total Potential Voidage shall not exceed 20% of the Internal Volume of the Disposal Container unless approved in advance by NWS.</p>	No changes proposed.
L2.17 Hazardous Waste, Hazardous Substances	<p>To fulfil regulatory requirements in relation to disposals at the Low Level Waste Repository, radioactive wastes that would be categorised as Hazardous Waste if they were not deemed to be radioactive waste, Hazardous Substances or Non-Hazardous Pollutants must be controlled. Such wastes are managed using the following categories:</p>	Changes are summarised in Subsection 7.3.3.

Paragraph	Current WAC	Our Conclusions
and Non-Hazardous Pollutants	<p>Category 1: Materials not requiring control but the quantities of which must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).            These materials are:</p> <ul style="list-style-type: none"> <li>• Aluminium metal/alloy</li> <li>• Asphalt or Tarmac not containing coal tar (generally that laid down post-1980)</li> <li>• Bitumen</li> <li>• Chromium metal/alloy</li> <li>• Cobalt metal/alloy</li> <li>• Copper metal/alloy</li> <li>• Fluoride (inorganic)</li> <li>• Iron metal/alloy</li> <li>• Magnesium metal/alloy</li> <li>• Mild steel</li> <li>• Molybdenum metal/alloy</li> <li>• Nickel metal/alloy</li> <li>• Phenol</li> <li>• Phosphate</li> <li>• Plastics (halogenated)</li> </ul>	

Paragraph	Current WAC	Our Conclusions
	<ul style="list-style-type: none"> <li>• Plastics (non-halogenated)</li> <li>• Stainless steel</li> <li>• Tin metal/alloy</li> <li>• Titanium metal/alloy</li> <li>• Vanadium metal/alloy</li> <li>• Vinyl chloride (un-polymerised)</li> <li>• Zinc metal/alloy.</li> </ul> <p>Category 2: Materials requiring an allocation. An allocation of the capacity of the Low Level Waste Repository will be given for each approved Waste stream. The allocation will be for a given volume of the waste and the contaminant quantities as described in the corresponding Waste Characterisation Form (Reference WSC-FOR-WCH). In cases for which there is not sufficient capacity, or in which the usage of the capacity would be grossly disproportionate to the volume of waste, this will be discussed with customers including the potential need for additional information. Customers shall ensure that the total disposal of such materials for each Waste stream does not exceed the allocation given by NWS. These materials are:</p> <ul style="list-style-type: none"> <li>• Arsenic all forms</li> <li>• Asphalt or Tarmac containing coal tar (generally that laid down pre-1980)</li> <li>• Beryllium all forms</li> <li>• Boron all forms</li> </ul>	

Paragraph	Current WAC	Our Conclusions
	<ul style="list-style-type: none"> <li>• Cadmium metal/alloy</li> <li>• Cyanide</li> <li>• Lead metal/alloy</li> <li>• Mercury metal/alloy</li> <li>• Selenium all forms</li> <li>• Tributyl phosphate (TBP)</li> <li>• Electronic and Electrical Equipment (EEE); <ul style="list-style-type: none"> <li>○ Type 1: Equipment with printed circuit boards (e.g. computers, telephones and stripped down circuit boards)</li> <li>○ Type 2: Plant items (e.g. electrolytic capacitors and transformers)</li> <li>○ Type 3: Electrical and electronic tools (e.g. corded drills and cordless drills)</li> <li>○ Type 4: Mercury-containing items (e.g. fluorescent light tubes, vapour lamps and mercury switches)</li> <li>○ Type 5: Rechargeable batteries (e.g. nickel-cadmium, nickel-metal hydride and lithium-ion).</li> </ul> </li> </ul> <p>Category 3: All other radioactive wastes that would be categorised as Hazardous Waste if they were not deemed to be radioactive waste, Hazardous Substances and Non-Hazardous Pollutants (with the exception of asbestos and Man-Made Mineral Fibres, see L2.18). These may</p>	

Paragraph	Current WAC	Our Conclusions
	<p>be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by NWS. The Form must include:</p> <ul style="list-style-type: none"> <li>• Details of the components that make the waste hazardous, their physical form and the levels at which they are present;</li> <li>• Total weight of each such component in each Waste Consignment;</li> <li>• Any treatment, conditioning or packaging taken to reduce their potential environmental impact and the results of any Leach Test using a method agreed with NWS.</li> </ul>	
<p>L2.18 Asbestos and Man-Made Mineral Fibres</p>	<p>A Waste Consignment may include an unlimited amount of Man-Made Mineral Fibres. The presence, type and quantity of such materials must be recorded in the waste description section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).</p> <p>A Waste Consignment may include amounts of asbestos and manufactured products containing asbestos as set out in Table 2.1. In all cases, the presence, physical form and quantity of such materials must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI). All asbestos-bearing wastes shall be packaged for handling and transport as detailed in HSE regulations and guidance. As a minimum, asbestos wastes that have not been Supercompacted shall be Double Wrapped.</p>	<p>No changes proposed.</p>

Paragraph	Current WAC	Our Conclusions												
	<p><b>Table 2.1: Acceptability of Asbestos and Asbestos-containing Materials</b></p> <table border="1"> <thead> <tr> <th>Material Type</th> <th>Examples</th> <th>Acceptability</th> </tr> </thead> <tbody> <tr> <td>Non-friable and low-friable asbestos containing manufactured products</td> <td>           Brake shoes            Low porosity, monolithic asbestos cement blocks and mouldings            Asbestos cement sheeting in mainly good condition         </td> <td>A Waste Consignment may include an unlimited amount</td> </tr> <tr> <td>Moderately friable asbestos-containing manufactured products</td> <td>           Fire doors and tiles            Ceiling tiles            Insulating boards            Badly damaged or degraded asbestos cement sheeting         </td> <td>A Waste Consignment may include up to one tonne of asbestos containing material</td> </tr> <tr> <td>Highly friable and loose asbestos forms</td> <td>           Asbestos cladding (e.g. pressed or sprayed cladding on pipework) and lagging            Loose asbestos lagging or insulation         </td> <td>A Waste Consignment may include up to 10 kg of such material</td> </tr> </tbody> </table> <p>Larger amounts than indicated above of moderately friable asbestos-containing manufactured products and highly friable and loose asbestos forms may be accepted for disposal but only on</p>	Material Type	Examples	Acceptability	Non-friable and low-friable asbestos containing manufactured products	Brake shoes Low porosity, monolithic asbestos cement blocks and mouldings Asbestos cement sheeting in mainly good condition	A Waste Consignment may include an unlimited amount	Moderately friable asbestos-containing manufactured products	Fire doors and tiles Ceiling tiles Insulating boards Badly damaged or degraded asbestos cement sheeting	A Waste Consignment may include up to one tonne of asbestos containing material	Highly friable and loose asbestos forms	Asbestos cladding (e.g. pressed or sprayed cladding on pipework) and lagging Loose asbestos lagging or insulation	A Waste Consignment may include up to 10 kg of such material	
Material Type	Examples	Acceptability												
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Moderately friable asbestos-containing manufactured products	Fire doors and tiles Ceiling tiles Insulating boards Badly damaged or degraded asbestos cement sheeting	A Waste Consignment may include up to one tonne of asbestos containing material												
Highly friable and loose asbestos forms	Asbestos cladding (e.g. pressed or sprayed cladding on pipework) and lagging Loose asbestos lagging or insulation	A Waste Consignment may include up to 10 kg of such material												

Paragraph	Current WAC	Our Conclusions
	<p>approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by NWS. The Form must include:</p> <ul style="list-style-type: none"> <li>• Description of the material and its condition;</li> <li>• Identification of the predominant mineral type, e.g. chrysotile (white), amosite (brown) and crocidolite (blue);</li> <li>• Total weight of material and estimated of amount of asbestos mineral;</li> <li>• Any treatment or packaging proposed to reduce the friability of the waste and/or reduce the potential environmental impact. Requests to Consign large amounts (several tonnes) of untreated asbestos in friable forms, especially of brown or blue asbestos, are liable to be refused.</li> </ul>	
<b>L3 Radiological Properties</b>		
L3.1 Radioactive Contamination	<p>The waste within a Waste Consignment for disposal at the Low Level Waste Repository must consist of waste deemed to be contaminated and not the primary contaminant itself. The weight of the Radioactive Contaminant shall not exceed 10% of the weight of the Waste Consignment. This limit may be exceeded but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification by NWS.</p>	No changes proposed.
L3.2 Radioactivity		

Paragraph	Current WAC	Our Conclusions
L3.2.1 Total Activity	<p>Customers shall ensure that Best Available Techniques have been adopted in the management of the waste.</p> <p>An allocation of the Radiological Capacity of the Low Level Waste Repository will be given for each approved Wastestream. The allocation will be for a given volume of the waste and the radionuclide levels as described in the corresponding Waste Characterisation document (Reference WSC-FORWCH). In cases for which the Radiological Capacity is not sufficient to accept the wastes, or in which the usage of the Radiological Capacity would be grossly disproportionate to the volume of waste, this will be discussed with customers including the potential need for additional information. Customers shall ensure that the total Activity of each Wastestream does not exceed the allocation given by NWS.</p>	<p>Proposed introduction of containers &gt;50MBq Ra-226 to only be accepted via a waste consignment variation. To be introduced to L3.2, potentially under 3.2.1 or a new separate WAC subcriteria may be required.</p>
L3.2.2 Specific Activity of Consignments	<p>The total Specific Activity of any Waste Consignment Consigned for disposal as Low Level Waste at the Low Level Waste Repository shall not exceed the following values:</p> <ul style="list-style-type: none"> <li>• 4 GBq t<sup>-1</sup> for all alpha-emitting radionuclides;</li> <li>• 12 GBq t<sup>-1</sup> for all other radionuclides.</li> </ul> <p>Only immediate packaging required to safely manage the waste, which includes the Disposal Container, can be included in the calculation of Specific Activity.</p>	<p>For potential acceptance of ILW, WAC would be developed and consulted upon.</p>
L3.2.3 Activity Heterogeneity and Discrete Items	<p>A Waste Consignment may include volumes of wastes or Discrete Items for which the Specific Activities exceed the maximum total Specific Activities for a Waste Consignment given in L3.2.2; however, the total Specific Activities averaged over the Waste Consignment must not exceed the maximum Specific Activities given in L3.2.2, waste must be managed in accordance with</p>	<p>Proposed update to Discrete Item Groups (Table 6.18, §6.5.2) and numerical underpinning (§6.5.1) to support the 'Reasonable</p>

Paragraph	Current WAC	Our Conclusions
	<p>regulatory guidance, and the Activity of Discrete Items within a Waste Consignment must be limited.</p> <p>Best Available Techniques must have been used to characterise, sort and segregate the waste to facilitate its management by optimal routes. Further guidance can be found in, 'The management of higher activity radioactive waste on nuclear licensed sites Section 4: Waste minimisation, characterisation and segregation', issued as Revision 2 of the Joint Guidance from the Health and Safety Executive, the Environment Agency and the Scottish Environment Protection Agency to nuclear licensees, February 2015.</p> <p>While the Specific Activity may vary across a Waste Consignment, and in some volumes, or Discrete Items may exceed the maximum Specific Activities for a Waste Consignment given in L3.2.2, waste volumes or Discrete Items that are known to exceed the maximum Specific Activities given in L3.2.2 must not be mixed with other wastes solely for the purpose of re-categorisation of the waste as acceptable for disposal at the Low Level Waste Repository.</p> <p>The total Specific Activity of a Waste Consignment must be a reasonable reflection of the Activity of the waste across the volume of the waste.</p> <p>Activities and Specific Activities of individual Discrete Items must comply with the following sum of fractions:</p> $\frac{Q_A}{DIL_A} + \frac{Q_{B1}}{DIL_{B1}} + \frac{Q_{B2}}{DIL_{B2}} + \frac{Q_C}{DIL_C} \leq 1$ <p>where <math>Q_N</math> is the total Activity or Specific Activity of group N radionuclides and <math>DIL_N</math> is the Discrete Item Limit for that group, depending on the mass of the Discrete Item. The Discrete Item Limits are shown In Table 3.1. The radionuclide groups in Table 3.1 are defined in Table 3.2.</p>	<p>reflection of activity' clause which will be consulted upon before any WAC change.</p>

Paragraph	Current WAC	Our Conclusions																								
	<p>Table 3.1: Discrete item limits.</p> <table border="1"> <thead> <tr> <th>Radionuclide</th> <th>Mass <math>\leq</math> 1 kg</th> <th>1 &lt; Mass &lt; 100 kg</th> <th>Mass <math>\geq</math> 100 kg</th> </tr> </thead> <tbody> <tr> <td>Group A</td> <td>0.001 GBq</td> <td>1 GBq t<sup>-1</sup></td> <td>0.1 GBq</td> </tr> <tr> <td>Group B1</td> <td>0.01 GBq</td> <td>10 GBq t<sup>-1</sup></td> <td>1 GBq</td> </tr> <tr> <td>Group B2</td> <td>0.3 GBq</td> <td>300 GBq t<sup>-1</sup></td> <td>30 GBq</td> </tr> <tr> <td>Group C</td> <td>1 GBq</td> <td>1000 GBq t<sup>-1</sup></td> <td>100 GBq</td> </tr> </tbody> </table> <p>Table 3.2: Radionuclide categorisation.</p> <table border="1"> <thead> <tr> <th>Group</th> <th>Radionuclides</th> </tr> </thead> <tbody> <tr> <td>Group A</td> <td>           Nb-94, Ag-108m, Sn-126            Ra-226            Th-229, Th-230, Th-232            Pa-231, Np-237, Am-243            Cm-247, Cm-248, Cf-251         </td> </tr> </tbody> </table>	Radionuclide	Mass $\leq$ 1 kg	1 < Mass < 100 kg	Mass $\geq$ 100 kg	Group A	0.001 GBq	1 GBq t <sup>-1</sup>	0.1 GBq	Group B1	0.01 GBq	10 GBq t <sup>-1</sup>	1 GBq	Group B2	0.3 GBq	300 GBq t <sup>-1</sup>	30 GBq	Group C	1 GBq	1000 GBq t <sup>-1</sup>	100 GBq	Group	Radionuclides	Group A	Nb-94, Ag-108m, Sn-126 Ra-226 Th-229, Th-230, Th-232 Pa-231, Np-237, Am-243 Cm-247, Cm-248, Cf-251	
Radionuclide	Mass $\leq$ 1 kg	1 < Mass < 100 kg	Mass $\geq$ 100 kg																							
Group A	0.001 GBq	1 GBq t <sup>-1</sup>	0.1 GBq																							
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Group B2	0.3 GBq	300 GBq t <sup>-1</sup>	30 GBq																							
Group C	1 GBq	1000 GBq t <sup>-1</sup>	100 GBq																							
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Paragraph	Current WAC		Our Conclusions
	Group B1	I-129 Pu-238, Pu-239, Pu-240, Pu-242 Am-241, Am-242m U-233, U-234, U-235, U-236, U-238 and mixtures thereof	
	Group B2	C-14, Cl-36, Ca-41, Sr-90 Zr-93, Mo-93, Tc-99, Cs-135, Cs-137 Pb-210, Ac-227 Pu-241, Cm-243, Cm-244, Cf-250	
	Group C	H-3, Co-60, Ni-59, Ni-63, Nb-93m, Sm-151, Eu-152 All radionuclides with half-life shorter than 10 years. Most radionuclides with half-life shorter than 20 years <sup>29</sup> .	
	<p>The amount of Activity in a Waste Consignment associated with Discrete Items must also be limited. The sum of fractions for the Activities associated with all the Discrete Items in a Consignment must not exceed ten calculated using the Discrete Item Limits for Discrete items of mass 100 kg or greater. Cutting up or dismantling of Discrete Items for disposal to produce a sum of fractions less than or equal to one is not allowed, even if the resulting items are placed in separate Consignments.</p>		

<sup>29</sup> The exceptions are radionuclides that have half-life shorter than 20 years but decay to moderately long-lived alpha emitters, notably Pu-241, Cm-244 and Cf-250.

Paragraph	Current WAC	Our Conclusions								
	Cutting up or dismantling is allowed to enable segregation of parts of a Discrete Item for management by different routes, including Consignment to the Low Level Waste Repository; or to reduce the size of a Discrete Item to fit into a Disposal Container.									
L3.2.4 Low-activity Sources	<p>Low Activity Sources may be Consigned to the Low Level Waste Repository subject to the following conditions.</p> <p>Customers must have tried to return sources to the supplier or manufacturer and considered alternative uses before Consigning sources for disposal.</p> <p>The Activity of any individual source shall not, at the date of Consignment, exceed the values set out in Table 3.3 where the radionuclide Groups are those specified in Table 3.2.</p> <p>Table 3.3: Activity limits for each radionuclide group.</p> <table border="1"> <thead> <tr> <th>Radionuclide Group</th> <th>Limit (MBq)</th> </tr> </thead> <tbody> <tr> <td>Group A</td> <td>1</td> </tr> <tr> <td>Group B1 and B2</td> <td>10</td> </tr> <tr> <td>Group C</td> <td>100</td> </tr> </tbody> </table> <p>In addition, the following conditions must be met:</p> <ul style="list-style-type: none"> <li>As much extraneous packaging and shielding must be removed from each source as possible and sources that might be potentially attractive should, as far as practicable, be disfigured;</li> </ul>	Radionuclide Group	Limit (MBq)	Group A	1	Group B1 and B2	10	Group C	100	Proposed update to Radionuclide Groups (Table 6.18, §6.5.4).
Radionuclide Group	Limit (MBq)									
Group A	1									
Group B1 and B2	10									
Group C	100									

Paragraph	Current WAC	Our Conclusions
	<ul style="list-style-type: none"> <li>• The sources should be disposed in a Small Container;</li> <li>• Sources must be packaged together in the smallest container required. The sources shall be mixed with sufficient cement grout, in the container, to provide reasonable containment of each source, with at least 100 ml of grout surrounding each source and the container 'topped up' with grout so as to minimise any air space or voidage and the tin closed tight;</li> <li>• Only one such container may be placed within a Waste Consignment and the overall Waste Consignment must be consistent with the 4 and 12 GBq t<sup>-1</sup> LLW limits;</li> <li>• A separate Waste Characterisation Form (Reference: WSC-FOR-WCH) must be approved by NWS for Low-activity Sources and include the following information: source registration references, the radionuclides, the total activity per source, any radioactive decay calculations, the number of discrete sources and the amount of grout per source;</li> <li>• Where more than one source is disposed, the total Activity of the Small Container must be such that:   <math display="block">[ IA + IB/10 + IC/100 ] / V \leq 5 \text{ MBq l}^{-1},</math> <p>where IA, IB and IC are the total Activities (MBq) of radionuclides of Groups A, B and C respectively and V is the volume of the container (litre).</p> </li> </ul>	
L3.2.5 Active Particles	Waste containing, or that may contain, Active Particles, or materials that may break down into Active Particles, may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by NWS.	No changes proposed.

Paragraph	Current WAC	Our Conclusions
L3.3 Fissile Radionuclides	<p>Waste Consignments containing uranium or plutonium radionuclides shall not exceed the following values:</p> <ul style="list-style-type: none"> <li>a) 150 g (U-233 + U-235 + Pu-239); or</li> <li>b) 300 g U-235 if the uranium enrichment does not exceed 5% U-235 with respect to total uranium; or</li> <li>c) 1000 g U-235 if the uranium enrichment does not exceed 1.6% U-235 with respect to total uranium; or</li> <li>d) unrestricted if the uranium enrichment does not exceed 0.93% U-235 with respect to total uranium.</li> </ul> <p>Categories (b), (c) and (d) above may also contain up to 15 g of (U-233 + Pu-239). The specific restrictions on U-233 are only applicable where the waste is derived from a plant or process that handled separated U-233.</p> <p>Waste Consignments containing fissile materials must also meet the criteria set out in L4.9 and L4.10.</p>	No changes proposed.
L3.4 Radiation	The maximum radiation level at any point on the external surface of the Disposal Container shall not exceed 2 mSv h <sup>-1</sup> and 100 μSv h <sup>-1</sup> at 2 metres.	No changes proposed for the current operating model.
L3.5 Contamination	External non-fixed contamination levels on the Disposal Container at the time of Consignment shall be as low as reasonably practicable and in any case not more than 0.4 Bq cm <sup>-2</sup> for all alpha-emitting radionuclides and 4 Bq cm <sup>-2</sup> for all other radionuclides averaged over an area of 300 cm <sup>2</sup> .	No changes proposed.

Paragraph	Current WAC	Our Conclusions																														
L4 Packaging and Transport Requirements																																
L4.1 Approved Disposal Containers	<p>Waste for disposal may be Consigned to the Low Level Waste Repository in any of the approved Disposal Containers listed in Table 4.1.</p> <p>Waste must be Consigned for disposal in accordance with the latest edition of IAEA SSR-6 (Regulations for the Safe Transport of Radioactive Material), as required by SI 2009 No. 1348 – The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment (Amendment) Regulations 2011 (known as the CDG Regulations), and the European agreement “Accord européen relatif au transport international des marchandises dangereuses par route” (known as the ADR) and RID (Regulations concerning the International Carriage of Dangerous Goods by Rail).</p> <p>Table 4.1: Approved disposal containers.</p> <table border="1"> <thead> <tr> <th>Disposal Container Type</th> <th>Design Ref.</th> <th>Column A (t)</th> <th>Column B (t)</th> <th>Column C (m<sup>3</sup>)</th> <th>Column D (m<sup>3</sup>)</th> </tr> </thead> <tbody> <tr> <td>1/3 Height Disposal Container</td> <td>TC03</td> <td>35</td> <td>40</td> <td>11.3</td> <td>13.0</td> </tr> <tr> <td>1/2 Height Disposal Container</td> <td>TC01</td> <td>35</td> <td>42</td> <td>17.9</td> <td>19.5</td> </tr> <tr> <td>2/3 Height Disposal Container</td> <td>TC06</td> <td>40</td> <td>42</td> <td>22.3</td> <td>26.8</td> </tr> <tr> <td>3/4 Height Disposal Container</td> <td>TC04</td> <td>35</td> <td>42</td> <td>24.8</td> <td>29.7</td> </tr> </tbody> </table>	Disposal Container Type	Design Ref.	Column A (t)	Column B (t)	Column C (m <sup>3</sup> )	Column D (m <sup>3</sup> )	1/3 Height Disposal Container	TC03	35	40	11.3	13.0	1/2 Height Disposal Container	TC01	35	42	17.9	19.5	2/3 Height Disposal Container	TC06	40	42	22.3	26.8	3/4 Height Disposal Container	TC04	35	42	24.8	29.7	<p>Strengthened HHISO to be added as an approved disposal container once design progressed.</p> <p>Some other container types may be removed should these be no longer available for use by consignors.</p>
Disposal Container Type	Design Ref.	Column A (t)	Column B (t)	Column C (m <sup>3</sup> )	Column D (m <sup>3</sup> )																											
1/3 Height Disposal Container	TC03	35	40	11.3	13.0																											
1/2 Height Disposal Container	TC01	35	42	17.9	19.5																											
2/3 Height Disposal Container	TC06	40	42	22.3	26.8																											
3/4 Height Disposal Container	TC04	35	42	24.8	29.7																											

Paragraph	Current WAC						Our Conclusions
	WAMAC Disposal Container	TC08	35	40	17.9	20.0	
	ISO Skip Disposal Container	TC05	17	22	8.5	11.4	
	<p>Notes:</p> <p>Column A: shows the maximum gross weight, in tonnes, for compliance with the Certificate of Approval for each container design. The maximum gross weight for any individual container is recorded in the Container Safety Convention approval plate on each container and shall be checked before the container is filled with waste.</p> <p>Column B: shows the maximum gross weight of the container, in tonnes, after in-fill grouting that can be routinely handled at the Low Level Waste Repository. Disposal Containers exceeding this value prior to being completely filled with grout will be classed as Overweight Grouted Containers in accordance with L4.5.</p> <p>Column C: shows the Internal Volume of each Disposal Container type, in m<sup>3</sup>, which is used for the purposes of assessing volumetric concentrations of materials in accordance with the Waste Acceptance Criteria.</p> <p>Column D: shows the Package Volume of each Disposal Container type, in m<sup>3</sup>, which is used for the purposes of calculating the disposal charges, independent of the actual volume of waste in the container.</p> <p>Disposal Containers damaged to the extent that they are required to be Consigned in an overpack container under an authorised Operational Concession (RSF 6.18.02_07) may be</p>						

Paragraph	Current WAC	Our Conclusions
	acceptable for disposal by NWS but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification.	
L4.2 Other Containers	Waste that cannot be readily Consigned in one of the approved Disposal Containers, as detailed in L4.1, may be acceptable for disposal in other containers by NWS but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification.	No changes proposed.
L4.3 Non-containerised Waste	Non-containerised waste may be accepted for disposal at the Low Level Waste Repository but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) with Suitable Supporting Justification by NWS.	No changes proposed.
L4.4 Packing	<p>Customers are responsible for loading the Disposal Container such that, as far as reasonably practicable, waste is packaged in such a way as to maximise the Packing Efficiency of the Disposal Container. Customers must, however, ensure sufficient grout penetration can still be attained to ensure compliance with the Waste Acceptance Criteria, in particular relating to voidage and settlement properties (L2.16).</p> <p>Waste must be packed in the Disposal Container such that no free movement can occur during normal transport conditions and each Consignment requires a signed Waste Loading Plan Information Form (WSC-FOR-WLP), which must reference either a valid Waste Loading Plan detailing the restraint configuration for transport, or which references the applicable section of the containers Packing and Handling Instruction.</p>	No changes proposed.

Paragraph	Current WAC	Our Conclusions
L4.5 Container Weights	The weight of a Disposal Container must not exceed 35 tonnes on receipt. Customers are responsible for loading the Disposal Container such that when it is filled with grout, of nominal density 1,800 kg m <sup>-3</sup> , the gross weight of the Disposal Container does not exceed the maximum gross weight in Column B of Table 4.1. Where customers calculate or anticipate that the Disposal Container will exceed the maximum gross weight after grouting, the Waste Consignment may still be accepted but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by NWS.	No changes proposed.
L4.6 Disposal Container Venting	The Disposal Container shall not be left un-vented for more than thirty days in advance of receipt at the Low Level Waste Repository.	No changes proposed.
L4.7 Disposal Container Labelling	Each Disposal Container shall be uniquely marked or labelled, in accordance with the IAEA Transport Regulations SSR-6 and the container designs Design Safety Report (DSR), so as to be legible for at least five years after delivery such that the customer and a Consignment serial number can be identified.	No changes proposed.
L4.8 Photographic Records	Customers are responsible for ensuring that, as far as reasonably practicable, photographic records of the filling of the Disposal Container with waste are produced and retained by the customer. Photographs should be taken when the Waste Consignment is approximately 25% full, 50% full, 75% full and 100% full. File references for the photographs must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).  Photographic records are not required for disposal containers containing only supercompacted pucks.	No changes proposed.

Paragraph	Current WAC	Our Conclusions
L4.9 Transport Regulations	<p>Waste must be Consigned for treatment or disposal in accordance with the latest edition of IAEA SSR-6 (Regulations for the Safe Transport of Radioactive Material), as required by SI 2009 No. 1348 – The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment (Amendment) Regulations 2011 (known as the CDG Regulations), and the European agreement “Accord européen relatif au transport international des marchandises dangereuses par route” (known as the ADR) and RID (Regulations concerning the International Carriage of Dangerous Goods by Rail) under one of the following classifications:</p> <ul style="list-style-type: none"> <li>• Excepted Package;</li> <li>• Low Specific Activity material (LSA I, LSA II);</li> <li>• LSA III (subject to confirmation of a Leach Test using a method agreed with NWS);</li> <li>• Surface Contaminated Object (SCO I or SCO II).</li> </ul> <p>Customers are responsible for ensuring compliance with the transport regulations and the Certificate of Approval for the specific Container Design including the requirements of any associated Packing and Handling Instructions.</p> <p>In addition, any Waste Consignment or Disposal Container that does not, in its own right, comply with the requirements of the current transport regulations and requires additional shielding or an overpack to achieve compliance may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and an authorised Operational Concession (RSF 6.18.02_07) by NWS.</p>	No changes proposed.
L4.10 Transport of	Waste transported in IP-2 containers may contain very low quantities or very low concentrations of fissile radionuclides when classified as Fissile Excepted Packages. In order to use the Fissile	No changes proposed.

Paragraph	Current WAC	Our Conclusions
Fissile Radionuclides	<p>Excepted Package classification, one of the fissile exemption criteria in the Transport Regulations must be satisfied and the justification documented.</p> <p>Note that the fissile excepted criteria do not always align with the criteria for Fissile Radionuclides in L3.3.</p> <p>Customers must contact NWS for advice if they intend to Consign waste to NWS that contains fissile radionuclides above the fissile excepted criteria, prior to loading waste.</p> <p>Customers must ensure they fulfil the requirements of both these Waste Acceptance Criteria and the Transport Regulations when Consigning fissile radionuclides to NWS.</p>	
L4.11 Part Loads	A Waste Consignment may not be Consigned to NWS if sent as a part-load with other materials that are not Low Level Waste on the same vehicle.	No changes proposed.
L4.12 Site Rules and Instructions	When delivering waste to NWS for disposal, the customer's representatives must observe the site rules and instructions at the Low Level Waste Repository.	No changes proposed.

### 8.3 Waste Consignment Variations and Disposability Assessment

Our WAC specify the physical, biogeochemical and radiological properties that each individual consignment of waste must meet. Compliance with these criteria ensures that disposal is consistent with the assumptions and assessment outcomes of the ESC and the Nuclear Safety Case (NSC). However, the need for a variation to the WAC may arise in several circumstances. For example, new waste types may be proposed for disposal, that do not conform to the original assumptions of the ESC – such as wastes containing a new contaminant not previously assessed, or wastes packaged in containers that were not considered as part of the ESC. In these cases, an assessment is required to determine whether the waste can be safely accepted, and the ESC and WAC may need to be revised accordingly.

There is no systematic strategy to develop cautious assessment models. However, our assessment models often include an element of caution for example when we need to make cautious assumptions about processes that are difficult to model. There may be circumstances where a less cautious approach might allow the safe acceptance of certain wastes that might otherwise be excluded.

Additionally, some waste management arrangements may not be acceptable on a repository-wide basis, but could be permissible in very specific, localised areas within the repository where the impacts can be demonstrated to remain within acceptable limits. This flexibility allows for optimal use of the facility while maintaining safety.

Finally, simplifications often arise during the process of translating the complex assumptions and outcomes of the ESC into robust, practical controls such as the WAC. This may involve setting measurable thresholds and, in some cases, these simplifications can introduce margins of safety between the safety envelope defined by the ESC and that defined in the WAC. Such margins ensure clarity and enforceability but may also lead to the need for variations or reassessments as new information or waste-types emerge.

When asked, we can undertake assessments under our waste consignment variation (WCV) process to see if wastes not meeting the WAC as stated are within the current safe operating envelope of the ESC or if the ESC could be revised to allow acceptance of the waste. These assessments are referred to as 'disposability assessments'. They can lead to revision of the ESC and stated WAC, based on the new understanding obtained.

Each variation is assessed by appropriate subject matter experts, which may include an ESC Technical Manager, the Nuclear Safety Case Manager, the ESC Manager for approval, and Operations Manager. We then document the basis for acceptance or rejection.

As part of our waste acceptance process, variations are 'scaled' according to the level of assessment required [149]. Scale 1, Scale 2 or Scale 3 may be applied, with Scale 3 variations requiring the most detailed assessment. There is a correlation between the level of scaling applied to a variation and the likelihood of the variation affecting the ESC. Scale 3 variations are summarised in the Annual Reviews. Since WAC Version 5 in 2016, 87% of

approved variations were Scale 1, 12% Scale 2 and 1% Scale 3. In some cases, variations can lead to additional constraints including the need for specific controls on emplacement. These are managed as part of emplacement operations but are not addressed further here.

Where deemed required by the Senior Lead - Waste Acceptance or the WAC Interpretive Authority, in addition to routine documentation required under the WAP, a disposability assessment will be required, presenting the acceptance case for a particular waste or consignment. Where required the disposability assessment will be subject to governance via the Strategic Waste Management Committee (SWMC) to obtain views of key internal stakeholders across the LLW Repository Director of Site, EHSS&Q, ESC, Waste Acceptance, Chief Technical Officer, Senior Lead Environmental and NDA Strategy. This process would identify any wastes deemed subject to notification of the EA under Permit condition 4.3.3. This process is how we have addressed "opportunity wastes". These are typically wastes that were previously categorised as ILW but have been recharacterised and demonstrated as LLW.

## **8.4 Emplacement Strategies**

We adopt an emplacement strategy for stacking waste packages in the vaults, partly in order to optimise the potential for reducing impacts in the future but also to reduce cap degradation through settlement. Identification of emplacement requirements as part of the waste consignment stage of the acceptance process is outlined in Section 8.1.2.2.

The number of consignments requiring consideration against the emplacement strategy is kept under review as part of the ESC Annual Review, to ensure it remains practicable. The number of containers triggering emplacements criteria has remained relatively constant over the period from April 2017 to March 2025 (22% of consignments received between April 2017 and January 2020, 28% of those received between February 2020 and March 2023 and 18% of those received in 2024). In 2025 the value is likely to be comparable to 2024. The waste and type of container influence the extent to which emplacement management is required. The success of diversion of LLW to other routes has led to the waste being consigned to the LLWR being more complex meaning emplacement requirements are likely to generally increase. However, there is a recent opposing trend. The Sellafield 2947 containers, also known as TC08 WAMAC product containers, do not require emplacement management.

In terms of current operations at the LLWR, grouting of consignments prior to vault emplacement is carried out on a campaign basis. Stacking arrangements within the vaults also provide a significant degree of flexibility, with several stacks being available at any one time. There is therefore a range of measures that are used to ensure that emplacement and stacking requirements are achievable and that the requirements of the ESC are met.

Consignments requiring specific emplacement are identified by LLWR Waste Acceptance Specialists as part of the waste acceptance process. We implement a calculation tool, within the Waste Consignment Information Form (WSC-FOR-WCI), to optimise the emplacement of

waste packages in consideration of the Emplacement Requirements specified in the Emplacement Strategy. Arrangements are in place to allow the operations team to identify and physically mark all such consignments, for example with a colour or digital code [150].

## 9 Summary

This report describes the systems, controls, and organisational arrangements that ensure operations at the LLWR remain within the assumptions, limits, and safety arguments underpinning the ESC. This section summarises the key changes in the ESC since the last major submission in 2011, implementation arrangements under the current operating model, changes that would be required if ILW were to be accepted, and an outline future work programme relating to implementation of the ESC.

### 9.1 Key Changes Since the 2011 ESC

Since the submission of the 2011 ESC but prior to the 2026 ESC, several changes have already been made to the way that the ESC is implemented, reflecting updates to the 'live' ESC in that period. These changes represent an evolution of our approach and draw upon the Environment Agency's review of the 2011 ESC, implementation of the 2011 ESC alongside our operational experience and Learning from Experience (LfE). Key improvements to waste controls since 2011 include the following.

- 1) Two revisions of the WAC, including revisions to existing WAC and the addition of new criteria. Revisions to the WAC included those on complexing agents and low-activity sources. New WAC that have been added apply to asbestos, non-radiological hazards and non-hazardous pollutants, discrete items and activity heterogeneity, and active particles. As part of revisions to the grouping of radiological hazards and non-hazardous pollutants, materials were grouped according to their management and respective disposal limits [71].
- 2) A new capacity management approach to effectively manage the volumetric, radiological and non-radiological capacities of the vaults, and apply an appropriate level of scrutiny during waste acceptance [147], and arrangements for monitoring capacity usage.
- 3) Implementation of non-radiological contaminant limits derived from a groundwater pathway assessment [151].
- 4) Implementation of emplacement strategies to optimise the safety and performance of the LLWR [117].
- 5) Review of the approach to voidage definition and estimation techniques, leading to new controls on voidage in the WAC [71].

Other improvements to the site's management processes since 2011 include those listed below.

- 1) The development of the DSS with the supporting RMS. The RMS systematically captures requirements for the existing vault design, and trench and vault closure engineering provisions, consistent with the ESC.

- 2) The introduction of an ECC on site. The ECC states the controls on waste acceptance derived from the ESC. The Certificate also lists equipment with an environmental function used to ensure Permit compliance, which is termed 'Environmental Equipment'.
- 3) Changes to the site change-control process to ensure that the implications for the ESC are assessed when changes to existing 'plant' and management arrangements are made, or where new plant are proposed.

## **9.2 Current Operating Model**

LLWR is an operational site with robust and appropriate implementation arrangements currently in place, such as the ECC, WAC, and WAP. These frameworks ensure consistency with the ESC and support the effective management of waste disposal operations. The ECC provides documented confirmation that all necessary environmental controls are in place, outlining the specific requirements derived from the ESC and listing the environmental equipment essential for maintaining Permit compliance. The WAC sets out the detailed criteria that must be met for waste to be accepted at the site, including specifications relating to radiological and non-radiological content, container standards, and controls on discrete items, activity heterogeneity, and low-activity sources. The WAP underpins the operational processes by establishing step-by-step procedures for waste consignors and site operators to follow, ensuring that all accepted waste aligns with the latest ESC requirements and site-specific safety and environmental standards.

These arrangements are regularly reviewed and updated to reflect ongoing improvements in site management processes, regulatory expectations, and advancements in environmental and safety assessments. For example, since the 2011 ESC we have introduced new WAC for asbestos, non-radiological hazards, and active particles, as well as the development of a new capacity management approach to optimise the use of vault space and monitor both volumetric and radiological capacities. The systematic management of requirements through tools like the RMS further strengthens the integration of engineering design, site operations, and the ESC.

## **9.3 Changes Required for ILW Acceptance**

The ESC includes certain less-hazardous ILW within the reference inventory for assessment purposes, primarily to facilitate discussions with regulators in light of evolving Government policy. However, ILW is not currently accepted at the LLWR and the focus of this report has been to describe updated arrangements for LLW. Should a proposal arise to accept ILW at LLWR, updates to our implementation arrangements would be required to ensure compliance with the ESC and maintain operational safety.

Although radiological and non-radiological capacities would remain unchanged, with ILW only being accepted within the existing defined capacities, several procedural and technical updates would be necessary. Specifically, the development of WAC tailored to ILW would be

required. The requirement for waste to meet the UK definition of LLW would be replaced by risk-based controls derived from ESC assessment cases set out in Subsection 6.4. WAC criteria on containers, grout, and external dose rates would be further developed. Complementary updates to the WAP and ECC would also be required, alongside a comprehensive review and revision of the NSC to address any new risks or operational considerations associated with ILW disposal.

Operational arrangements associated with updated engineering designs and emplacement methods would need to be thoroughly reviewed and, where appropriate, amended to accommodate ILW, ensuring that all processes remain within the established safety envelope.

There would be more ILW available for disposal that can be accommodated by the total radiological capacity. We would therefore develop a plan for allocating disposal capacity. This is because prioritising waste on a 'first-come, first-served' basis does not guarantee best use of available space, though timing may influence decisions. This plan would outline expected waste disposals over LLWR's lifetime. Waste will be accepted according to the plan, provided it meets the WAC or an agreed variation. We would create this plan in collaboration with the NDA and waste consignors, providing consignors with certainty for decommissioning and waste management plans.

Unlike for LLW, to manage the heterogeneous nature of ILW disposal, ILW acceptance would require controls on total activity released over a given erosion interval, not just total vault activity. We must control how much radioactivity could be released over time as the vaults erode. To do this, the total space in the vaults would be virtually divided into several long, narrow sections running parallel to the coast, with each section given its own limit on how much radioactivity it can contain. These limits would be regularly checked and reviewed, as part of the ESC review cycle, to make sure the distribution of waste remains within regulatory guidance levels.

Furthermore, accepting ILW would necessitate a formal Permit variation and may require a change in planning permission, both of which would require consultation with the Environment Agency and other relevant stakeholders.

#### **9.4 Future Work Programme**

A programme of work to update the WAC, WAP and associated arrangements such as emplacement is being established and will be discussed with the Environment Agency and other stakeholders. Additionally, we will update our DSS and monitoring programme to reflect the updated understanding from the ESC.

Necessary changes will be brought into operation in a planned and phased manner, with priority given to any aspects that if not enacted would potentially have negative environmental safety implications.

Our management system outlines the procedures to be followed to update the WAC and WAP including the required internal consultation with affected departments and external consultation with consignors to the LLWR. We will give additional consideration to the management of waste treatment, loading and storage operations that are already underway on consignor sites.

As required by our Permit, we will consult with and notify the Environment Agency on revisions to the WAC and waste acceptance arrangements.

Relevant changes include the following.

- 1) Updating the WAC to incorporate new and revised criteria, including those related to discrete items, activity heterogeneity, and low-activity sources (summarised in Table 8.4). Updates will be made in a phased manner, following relevant consultation and notifications under condition 4.3 of the Permit.
- 2) Updating vault capacities and emplacement criteria to reflect the latest ESC assessment calculations (Sections 6 and 7).
- 4) We propose to operate to the C-14 and Ra-226 capacities set out in Table 6.4 until the strengthened HHISO is in use. This capacity is lower than the current capacity. Once we implement the strengthened container, we would recalculate the remaining capacity for C-14 based on its use.
- 3) Enhancing our monitoring of ongoing disposals, including trend monitoring of discrete item activities to ensure they remain consistent with the assumptions in the ESC (Subsections 3.4 and 6.5.2).
- 4) Continuing the development of the RMS to systematically capture, update and manage requirements as engineering design and implementation progresses in line with the 2026 ESC (Subsection 3.2), to include the following.
  - a) Updates to the requirements set, to make it consistent with updated optimised design set out in the ESC; for example adding in new requirements for the strengthened HHISO containers.
  - b) Development and management of a full verification and validation plan for ESC-related requirements.
  - c) Periodic updates and maintenance of the RMS to reflect requirements management best practice.
- 5) Adoption of a capacity usage index (CUI) to further scrutinise whether individual waste stream represent a proportionate and BAT use of the site's capacity.

Such changes would be subject to further consultation with the Environment Agency and consignors, amongst other stakeholders, alongside relevant notifications to the Environment Agency under condition 4.3 of the Permit. Some may also require a variation to the Permit.

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