

The 2011 Environmental Safety Case

Waste Acceptance

LLWR/ESC/R(11)10026

May 2011



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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 radioactive waste. The LLWR is owned by the Nuclear Decommissioning Authority (NDA) and operated on behalf of the NDA by a Site Licence Company (SLC) – LLW Repository Ltd.

We, LLW Repository Ltd, are committed to operating the LLWR as a safe and efficient facility that provides a continuing option for the disposal of low-level radioactive waste in the UK. This will be achieved consistent with good practice for the near-surface disposal of radioactive waste, in accordance with environmental and health and safety regulation and guidance, and in compliance with the terms of our Nuclear Site Licence and Permit to dispose of radioactive waste.

This report is one of a series of reports that present the evidence underpinning the 2011 Environmental Safety Case for the LLWR – the 2011 ESC. The report has been prepared by the Environmental Safety Case Project and is issued under the authority of the Managing Director of LLW Repository Ltd.

ESC objectives

Under the terms of our Permit granted by the Environment Agency, we are required to submit an Environmental Safety Case (ESC) for the LLWR no later than 1st May 2011 and at intervals thereafter as requested by the Agency. The ESC:

- presents the arguments and evidence concerning the environmental safety of disposals of solid radioactive waste at the LLWR, at present and in the future, consistent with the Agency's Guidance on Requirements for Authorisation;
- provides a basis for the environmentally safe management of the site by the SLC, and regulation of the site by the Agency, including setting of conditions on its future management and acceptance of waste.

The ESC is addressed primarily to the Agency and is intended to inform and enable their regulation of the LLWR. It also provides a plan for the future management of the LLWR and a baseline against which proposed changes in the plan for the development of the facility can be tested. As such, it will be of interest to our other stakeholders, both local and national.

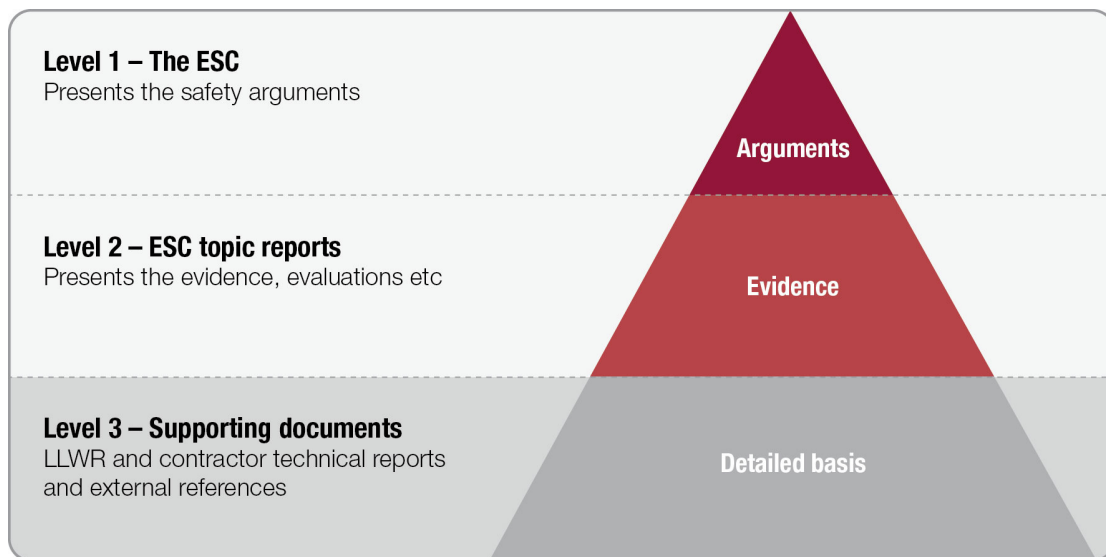
ESC document plan

The 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 this 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, and assessments.

This is a Level 2 report. The ESC Level 1 and 2 reports are listed in the table at the end of this Preface, which also shows for the Level 2 reports the set of arguments for which each report mainly provides evidence. The ESC is supported by a large

number of technical and scientific reports and references that we refer to as ‘Level 3’ documents.



The ESC documentation concept

Scope and audiences

The 2011 ESC is based on an optimised ‘Site Development Plan’ developed under our Environmental Safety Strategy. The Plan sets out our proposals and assumptions on operations, remedial activities, vault design, capacity and future waste disposal practice, closure design and management up to the end of management and regulatory control. It provides a basis for our quantitative assessments. The Plan is flexible, however, and will be amended as necessary in the light of UK radioactive waste management needs, operating experience, results of monitoring, future iterations of the ESC, regulatory and planning guidance and decisions, and stakeholder views.

The safety arguments set out in the Level 1 report comprise arguments concerning the development and safety of the Site Development Plan. The Level 1 report focuses on the arguments in principle, referring to the more detailed and quantitative evidence that is presented in the Level 2 reports. The main features and findings of the supporting reports are presented, demonstrating that the Site Development Plan is optimised, and that the assessed safety is consistent with the regulatory guidance over the lifetime of the facility, including after closure. The Level 1 report is intended to be complete enough to inform managers from the Environment Agency, Government ministries and local government representatives and officials on the environmental safety of disposal of radioactive waste at the facility. It is also intended to be an entry point to the safety case for the Agency’s technical staff and assessors.

The Level 2 reports present the evidence that underpins our safety arguments, including descriptions of our management framework, system understanding, optimisation, assessments and proposed conditions for acceptance of waste. The Level 2 reports are primarily addressed to the Agency’s Nuclear Regulator for the site and technical staff, and may be of interest to experts in specific technical fields. To fully satisfy themselves, however, for example, to find supporting information and

details of the model formulations and data used, technical specialists and reviewers in specific topic areas may need to refer to Level 3 documents.

We have also produced a Non-technical Summary of the ESC, to help a wider group of stakeholders understand its nature, conclusions and implications.

Level 1	
The 2011 Environmental Safety Case – Main Report [1]	
Level 2	
Management and dialogue	Management and Dialogue [2]
System characterisation and understanding	Site History and Description [3] Inventory [4] Engineering Design [5] Near Field [6] Hydrogeology [7] Site Evolution [8] Monitoring [9]
Optimisation and Site Development Plan	Optimisation and Development Plan [10]
Assessments	Environmental Safety During the Period of Authorisation [11] Assessment of Long-term Radiological Impacts [12] Assessment of Non-radiological Impacts [13] Assessment of Impacts on Non-human Biota [14] Waste Acceptance [15] Assessment of an Extended Disposal Area [16]
Audit	Addressing the GRA [17]

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Executive Summary

This report describes the results of a programme of work to identify waste acceptance criteria (WAC) and associated waste control arrangements for the LLWR on the basis of the understanding generated by the 2011 Environmental Safety Case (ESC).

In carrying out this work, emphasis has been placed on developing an approach in accordance with regulatory guidance, and to provide a tool to support LLWR site management. In deriving the approach, requirements provided by the Environment Agency in response to previous submissions and best practice guidance from relevant international bodies have also been considered.

The report identifies controls and associated WAC that are consistent with the understanding generated and requirements identified throughout the ESC. It is important that the WAC take into account the outcomes of assessments concerning the potential environmental impacts from both disposed radionuclides and non-radiological contaminants, and reflect the data and assumptions underpinning those assessments in a consistent way. Revised radiological limits have been derived on the basis of compliance with dose constraints and risk and dose guidance levels set out in the Environment Agency's guidance.

In terms of the material composition of the wastes, additional controls need to be placed on the biodegradable content of the wastes in order to ensure appropriate long-term performance of the engineered cap. Additionally, we will require that wastes primarily in powder form should be conditioned prior to acceptance in order to ensure their immobility.

A revised set of controls has been derived to manage the activity content of the wastes consistent with the ESC. These are primarily based on a 'Sum of Fractions' approach, used elsewhere in the UK and internationally, that takes account of potential contributions to radiological impact from many radionuclides. Limits have been derived for total vault disposals based on the assessment results for the groundwater and gas pathways and coastal erosion of the site. Limits on activity concentrations have been derived based on the human intrusion assessment results.

The work has shown that emplacement strategies for the stacking of certain wastes in the vaults are necessary. This is partly to meet the requirements for cap performance, for which controls on the quantities of biodegradable wastes and metals are required. We have identified that certain higher activity low-level wastes should be excluded from upper stack positions, and in some cases not co-located in the vaults, in order to limit the potential impacts from human intrusion.

The report shows how the WAC and associated waste control arrangements will provide a tool to support implementation of the following requirements throughout future LLWR operations.

- Management of the radiological capacity of the LLWR, consistent with the ESC and relevant Permit conditions.
- Application of additional consignment limits to control activity concentrations.
- For those wastes that are of the greatest potential significance in environmental safety terms, additional emphasis is placed on ensuring that the approach to disposal represents the use of Best Available Techniques for the management of the wastes.

- The use of emplacement strategies for particular waste streams and waste consignments where specific arrangements are required to demonstrate optimisation with respect to environmental safety.
- Provision of a basis for revisions to the WAC and the waste acceptance arrangements that incorporate the assumptions and findings of the ESC.

On completion of the 2011 ESC, we will take forward the finalisation of the revised WAC and waste control arrangements.

In summary, the basis for revised waste control arrangements has been systematically developed, based on the results of the 2011 ESC, and consistent with regulatory guidance. The implementation of these arrangements, will provide a basis for ensuring the environmental safety of the site in both its operational phase and in the longer-term. It is intended that the approach to implementation will be the subject of engagement with the Environment Agency and will include considerations necessary to ensure compliance with the Permit for the site.

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1 Introduction

1.1 Objectives

In order to ensure the safety of any waste disposal site, an essential feature is the definition and application of a set of waste acceptance and control arrangements. Such arrangements encompass:

- The systems, within the organisation managing the disposal facility, that control the approval and acceptance of waste for disposal.
- Waste acceptance criteria (WAC) that represent the '*quantitative and / or qualitative criteria, specified by the operator of a disposal facility and approved by the regulator, for solid radioactive waste to be accepted for disposal*' [18].
- Operational procedures and practices, including measures that incorporate any specific waste emplacement restrictions necessary in order to comply with safety requirements.

Safety in this context relates to ensuring the operational safety of workers, the safety of members of the public and minimisation of impacts on the environment. Relevant timeframes include the Period of Authorisation (PoA) and also long-term when any institutional controls may have lapsed.

The need for WAC is a key requirement of the environment agencies' guidance on authorisation requirements for the near-surface disposal of radioactive waste (the GRA) [18]. GRA Requirement 13 requires WAC should be established and Requirements 8 and 12 are also particularly relevant. These requirements are discussed in more detail in Subsection 3.1.

WAC and the associated control arrangements are an essential part of ensuring compliance with the ESC, in particular in terms of meeting regulatory requirements on dose limits, risk and dose guidance levels, and those aspects of optimisation associated with waste characteristics.

The objectives of this report are to describe:

- The methodologies by which revised WAC and waste control requirements for the Low Level Waste Repository (LLWR) have been derived and implemented, ensuring consistency with the arguments and assessments presented elsewhere in the Environmental Safety Case (ESC), and in accordance with regulatory guidance and requirements.
- The resulting WAC requirements and waste control arrangements, including requirements on waste emplacement.

1.2 Scope

The WAC and associated waste control arrangements described in this report are those applicable to the disposal of low level waste (LLW) at the LLWR.

The existing WAC [19,20], together with a description of the associated control arrangements, are provided by LLWR for use by waste producers to enable them to assess their wastes for potential disposal at the LLWR and to manage any subsequent disposals. They are also provided to regulators and other interested parties in order to demonstrate the means of control of wastes disposed of at the site.

This is important in order for the regulators and other stakeholders to have confidence in the control arrangements. The current waste acceptance process and associated WAC for the LLWR have developed over the years of operation of the site and have been informed by the experience gained during that time. They include consideration of all the necessary characteristics of the wastes for the safe operation and long-term environmental performance of the site.

The WAC for the LLWR are based on consideration of a range of factors including: operator safety, environmental safety, operational aspects, administrative requirements, and related regulatory requirements and guidance. The purpose of this work has been to derive an approach to ensure controls will be consistent with the requirements and assumptions identified across the ESC. A range of additional requirements that are not of direct relevance to environmental safety and thus not specifically addressed by the ESC, for example those based on operational worker safety considerations, are summarised in this report but not discussed in detail.

An important component of the ESC concerns assessing the potential impacts that might arise from expected future disposals. The understanding gained from relevant aspects of the ESC needs to be translated into effective controls on individual waste streams and waste consignments that might be disposed of at the site. These controls need to be consistent with the requirements of the safety strategy underpinning the ESC, the assumptions, results, and understanding of impacts of the assessment work, and the associated regulatory requirements.

Such controls provide the framework and details required for ensuring that inventory and waste form related aspects of the safety strategy are implemented by means of the waste acceptance process operated by LLWR and by waste consignors. These are part of the control measures necessary to provide assurance of environmental safety. For example, environmental safety assessment calculations presented elsewhere in the ESC are utilised directly to derive acceptable levels for the radioactive content of wastes. Similarly, other safety-relevant requirements identified elsewhere in the ESC (for example on limiting voidage to minimise future settlements) are also defined in the WAC.

This report therefore presents:

- The basis for derivation of WAC and control measures, addressing the above requirements.
- Implications for waste acceptance procedures that act to control the inventory of the LLWR and its capacity to accept LLW.
- Emplacement strategies to meet performance requirements and consignment limits identified for particular waste types.

Subsequent to submission of the 2011 ESC, detailed finalisation of the revised WAC and waste control arrangements will be taken forward by LLWR. It is intended that the approach to implementation will be the subject of engagement with the Environment Agency, and will include considerations necessary to ensure compliance with the Permit for the site [21]. Discussions with waste consignors will also be required to facilitate the efficient introduction of the required changes. These aspects are discussed further elsewhere in this report.

There are a wide range of interactions between this current report and other ESC reports. The principal links are:

- '*Inventory*' [4]. This summarises projections of future UK LLW arisings including those intended for disposal at the LLWR.

- ‘*Engineering Design*’ [5]. This describes the design and expected performance of engineered features associated with the disposal vaults (and the trenches) and site closure measures. The performance of certain aspects of the engineered system is related to certain assumptions regarding the disposed waste form and it is important that the WAC ensure future disposals are consistent with related requirements.
- ‘*Near Field*’ [6]. This describes the expected evolution of the wastes with time. The WAC must therefore address performance-related requirements arising from the understanding of projected evolution of the near field.
- ‘*Optimisation and Development Plan*’ [10]. This summarises the evidence and logic underpinning demonstration of optimisation in the management, design and operation of the LLWR. The WAC and associated controls will provide an important function in terms of ensuring appropriate implementation of the optimised approaches identified.
- Reports [11], [12] and [13] present the outcomes of assessments, informed by quantitative calculations, concerning the radiological impacts during the PoA [11] and longer-term [12] and non-radiological impacts [13]. The outcomes of these assessments provide a basis for the derivation of limits on the inventory of radiological and non-radiological contaminants within the wastes.

1.3 Structure

The structure of the report reflects the objectives, scope and approach to the work as described above. Hence, in this report:

- Section 2 describes our approach to the consideration of waste acceptance issues and the context in terms of current waste acceptance arrangements.
- Section 3 sets out the UK regulatory context relevant to derivation of WAC. The international context in setting WAC is also discussed.
- Section 4 presents our considerations on the controls required on waste form and physical characteristics of wastes that potentially influence the engineering components of the waste disposal system.
- Section 5 considers the controls required on waste properties that have the potential to influence release of contaminants or transport in the environment.
- 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 for individual low-activity sources and controls for fissile radionuclides.
- Section 7 gives our considerations on controls to limit the non-radiological inventory for the site.
- Section 8 describes our approach to the implementation of this work including waste acceptance arrangements, revised WAC and waste emplacement strategies.
- Section 9 presents our conclusions of the work on waste acceptance including the key findings and their implementation.

A list of acronyms used in the report is given in Appendix 1. A general glossary for the ESC is appended to the ‘*Main Report*’ [1].

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2 Approach

The main aims of this report are twofold. Firstly, the report sets out an approach for the derivation of WAC, taking into account the understanding generated and assessments made elsewhere in the ESC. Secondly, the report describes the WAC and associated waste control arrangements, and shows how they will be implemented in order to build confidence in long-term environmental safety.

The approach presented is based upon the following.

Definition of context

WAC provide an important planning and operational tool to NDA, LLWR and waste consignors. WAC are based on a range of factors including regulatory requirements and international experience.

Assessment

The understanding of performance-relevant aspects demonstrated across the ESC has been utilised to identify aspects that need to be reflected in waste control arrangements.

- The approach firstly considers characteristics of the waste form and physical characteristics of wastes that provide important assumptions in terms of the performance of closure engineering components (for example the final cap).
- Secondly, other waste form properties that have the potential to influence release of contaminants or transport of those contaminants in the environment are considered. Any necessary constraints on waste form and composition are identified.
- Thirdly, the outcomes of detailed assessments of performance undertaken for the ESC are used to derive the basis for revisions to the controls on the radiological and non-radiological inventories of wastes.

Implementation

Approaches for the practical implementation of the requirements are described, for example any changes necessary to LLWR's management arrangements for the specification, acceptance and emplacement of wastes. Additional requirements, potentially necessary to ensure compliance with the Permit for the site [21], are discussed. Implications for waste consignors and their waste management arrangements and practices are also explored.

The approach described is illustrated schematically in Figure 2.1

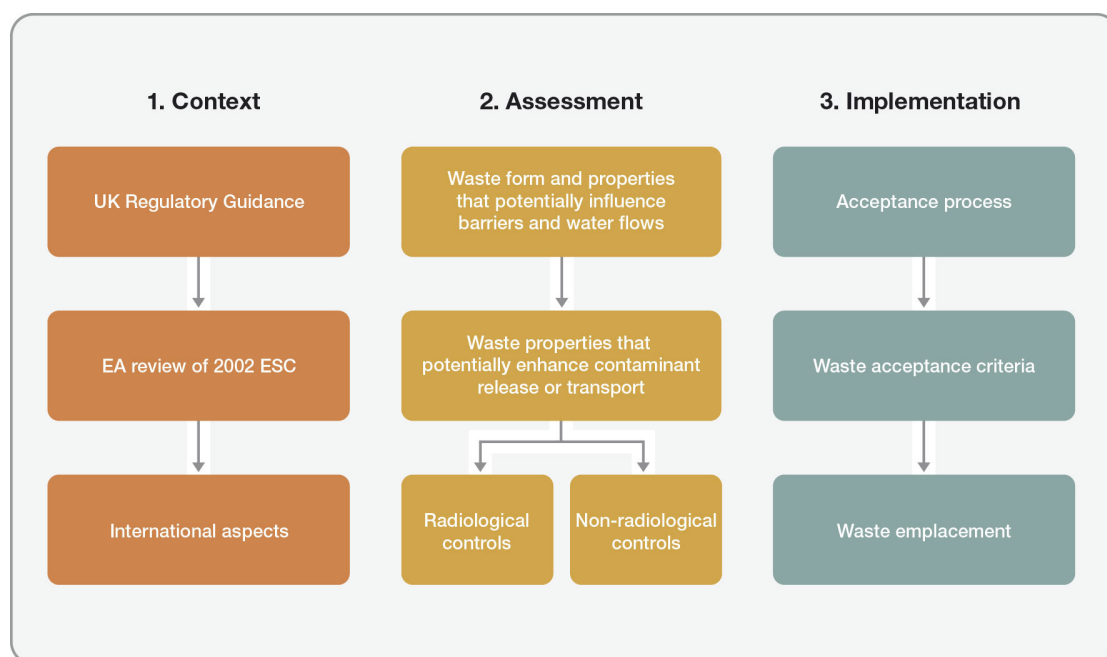


Figure 2.1 Outline approach adopted in this report

The WAC are an essential component of the procedures that control the wastes to be disposed at the LLWR and it is important that the context for their use is recognised. The WAC are part of an overall waste acceptance process. Procedures describe the arrangements that waste consignors and LLWR must follow for consigning and accepting waste to the LLWR for treatment and / or disposal. These procedures form part of the waste services contract held by customers. The procedures, and LLWR associated management arrangements, together provide the overall set of controls required to manage disposal of LLW to the site.

The procedures include a series of stages (discussed in more detail in Subsection 8.1). The important aspects of this process can be summarised as:

- **Capacity management.** This stage provides a basis for managing the capacity of the site to accept LLW, noting both radiological and volumetric aspects of capacity, on both an annual and a lifetime basis.

The volumetric capacity of the site is such that it cannot accept all potential LLW expected to be generated in the UK in the coming decades. It is important therefore that the LLWR is only used for those wastes that need to be disposed at such a facility and not for wastes that might be more appropriately managed by other means.

The radiological inventory of the site requires control, primarily based on environmental safety considerations, to ensure that impacts remain consistent with regulatory requirements both during and after its operational lifetime. Procedures relating to this aspect of the waste acceptance process therefore focus on waste forecasting requirements on waste consignors and facility management by LLWR in terms of acceptance of wastes given available capacity.

- **Waste characterisation and assurance.** The waste characterisation process 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 provide an accurate declaration of the radioactive content of the waste during the waste consignment process. Customers are required to

provide us with the necessary documentation to demonstrate that their waste management arrangements and procedures comply with the requirements of both the waste acceptance arrangements and the WAC. We undertake customer audits and assurance monitoring of waste consignments to further build confidence in compliance.

- **Waste consignment and waste receipt.** The key component of this stage is that appropriate information is provided on each Waste Consignment Information Form, detailing the contents of a specific container of waste. This information is checked by us prior to receipt of each consignment and, after subsequent disposal of the waste, the completed forms become the lifetime records of waste disposed of at the LLWR. Any specific requirements in terms of acceptance, treatment and vault emplacement are identified at this stage. On arrival of each consignment, waste receipt checks and assurance monitoring are carried out to confirm that the consignment complies with all relevant requirements.

The requirements necessary to provide compliance with environmental safety are supported both by application of the WAC and the arrangements within LLWR for the acceptance and subsequent emplacement of the wastes. The rationale for revisions to the WAC on the basis of the understanding presented in the ESC is described in Sections 4 to 7 and summarised in Section 8. The additional requirements identified in terms of waste control arrangements and waste emplacement procedures at the LLWR site are also identified in Sections 4 to 7 and discussed further in Section 8.

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3 Regulatory and International Context

3.1 UK Regulatory Requirements Relating to WAC

The primary source of UK regulatory guidance and requirements relating to near-surface radioactive waste disposal facilities is the GRA [18]. This sets out the overall requirements that the UK environment agencies expect a developer or operator of such a facility to fulfil when applying for an authorisation (now a permit) to develop or operate such a facility. It sets out the radiological protection requirements and guidance on what is expected of environmental safety cases. The GRA also describes expectations concerning what should be addressed in the WAC for a near-surface radioactive waste disposal site.

The 2011 ESC is a formal submission that presents the arguments and evidence concerning the environmental safety of disposals of solid radioactive waste at the LLWR, at present and into the future, consistent with the GRA. It also provides a sound basis for our future management of the site, and regulation of the site by the Environment Agency, including the setting of conditions for its future management and acceptance of waste.

The '*Main Report*' [1] sets out an optimised safety strategy and supporting arguments demonstrating how the requirements of the GRA are met by the submission. For the purposes of the present document, it is relevant to highlight those requirements from the GRA that are particularly pertinent to setting WAC. In summary, the WAC must be consistent with the safety strategy set out in the main ESC document, in order to demonstrate that the following will be achieved:

- Radiological risks to individual members of the public and the population as a whole will be as low as reasonably achievable. (From GRA Principle 2 and Requirement R8);
- Protection against any non-radiological hazards is 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. (From GRA Principle 3 and Requirement R10);
- During the 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. (From GRA Requirement R5);
- 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. (From GRA Requirement R6);
- 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 exposures continuing over a period of years to around 20 mSv per year for short-term exposures. (From GRA Requirement R7).

In addition, the Environment Agency has issued interim guidance to supplement the GRA in terms of the more recent groundwater provisions of the Environmental Permitting (England and Wales) Regulations 2010 (EPR10) [22]. Of note is the additional requirement that the radiation dose to members of the public through the groundwater pathway during the PoA of the facility is consistent with, or lower than, a dose guidance level of 20 μ Sv per year.

It is useful to differentiate constraints from guidance levels. The GRA clarifies that constraints represent limits that must be complied with, but that 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.

For the purposes of deriving radiological limits for WAC, guidance levels provide important benchmarks and thus are typically used as if they are constraints when calculating capacities. This is the basis for the approach taken in this document. However, in specific circumstances, it may be that WAC can be specified that might lead to radiological capacities that would challenge guidance levels. In such cases, very clear arguments are required to demonstrate the principle of optimisation, i.e. that all necessary considerations being taken into account, disposals of such wastes to a facility represent the optimal management approach.

A key requirement of the GRA [18] is for disposal site operators to set WAC. The UK environmental agencies define WAC as '*Quantitative and/or qualitative criteria, specified by the operator of a disposal facility and approved by the regulator, for solid radioactive waste to be accepted for disposal.*'

Specific requirements in the GRA relating to WAC are given below.

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. (GRA paragraph 6.4.26)

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. (GRA paragraph 6.4.27)

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. (GRA paragraph 6.4.28)

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 environmental safety 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 case. We shall also expect the developer/operator to demonstrate that

the possibility of a local accumulation of fissile material, such as to produce a neutron chain reaction, will not arise. (GRA paragraph 6.4.29)

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. (GRA paragraph 6.4.30)

The GRA [18] also contains a number of further references to additional requirements in relation to WAC. These are given below.

Within Requirement R7: Human intrusion after the Period of Authorisation:

For wastes with a significant content of long-lived radionuclides, potential doses around the dose guidance level may be possible for human intrusion scenarios in which significant amounts of waste are disturbed. The results of these scenarios are likely to be important in deriving facility-specific authorisation limits and conditions, such as inventory limits and allowable activity concentrations for specified radionuclides. We shall expect the developer/operator to propose such limits and support these proposals with suitable arguments. (GRA paragraph 6.3.52)

Requirement R8: Optimisation

The choice of waste acceptance criteria, how the selected site is used and the 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 period of authorisation and afterwards, are as low as reasonably achievable (ALARA), taking into account economic and societal factors. (GRA paragraph 6.3.56)

Within Requirement R10: Protection against non-radiological hazards:

Some waste disposed of at a facility receiving radioactive waste may be potentially harmful wholly or partly because of its non-radioactive properties. There are nationally acceptable standards for disposing of hazardous waste. However, these standards may not be suitable to apply directly to waste that presents both radiological and non-radiological hazards. Accordingly, these standards need not necessarily be applied, but 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. This could be achieved by ensuring that materials posing non-radiological hazards are contained within the facility over timescales at least as long as those provided for by the barriers at a site for disposal of non-radiological hazardous wastes. (GRA paragraph 6.4.2)

Requirement R12: Use of site and facility design, construction, operation and closure

The developer/operator of a disposal facility for solid radioactive waste 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. (GRA paragraph 6.4.16)

Within Chapter 7: Environmental safety case:

The environmental safety case will provide an input to deriving facility-specific regulatory limits and conditions, and should help to underpin the developer/operator's

waste acceptance criteria and emplacement requirements. It may also help to guide the monitoring of discharges for compliance with the authorisation, and the environmental monitoring programme for the site and the surrounding area. (GRA paragraph 7.2.18)

We shall expect the developer/operator to demonstrate in the environmental safety case that optimisation considerations have been applied in all relevant decisions and at all relevant steps. Relevant steps include the choice of waste acceptance criteria, how the selected site is used and the design, construction, operation, closure and post-closure management of the disposal facility (see Requirement R8). (GRA paragraph 7.3.34)

Key points from the above can be summarised by the following requirements:

- WAC need to be consistent with controls required to implement the safety strategy presented in the 2011 ESC.
- Controls on radioactive and non-radioactive contaminant inventories, including fissile radionuclides, are required.
- Consideration of aspects of the waste form and composition relevant to minimising release of contaminants from the facility must be considered. These include controls relating to the chemical and physical form and durability of the wastes, including their potential future biogeochemical evolution.
- Support to operational requirements such as safe transport and handling at the facility is also required.

Whilst the GRA provides guidance on requirements for WAC, it is also important to note that the Permit for disposals at the LLWR [21] includes additional requirements of relevance to WAC. In particular these include:

- Consignment limits of 4 and 12 GBq t⁻¹ LLW for alpha emitting radionuclides and all other radionuclides respectively.
- Annual 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.

3.2 Environment Agency Review of the 2002 Safety Cases

The previous safety case for the LLWR was set out in the 2002 Safety Cases [23,24]. The Environment Agency's review of the 2002 Safety Cases included findings relating to WAC [25]. The Environment Agency's findings took into account the version of the GRA that applied at that time [26]. It is valuable to consider the outcomes of this review in order to help inform judgements on the approach to specifying WAC for the 2011 ESC. The outcomes provide a useful source of facility-specific regulatory guidance on these topics.

An important conclusion from the Environment Agency review was that the site operator should document the derivation of the WAC and update them at periodic intervals to ensure that they remain consistent with the most recent environmental safety case. This is a primary objective of the current report.

The current Permit for the site includes limits on disposals based on a previous assessment for the site [27], from which radiological capacity values were derived. A radionuclide-specific radiological capacity value is the quantity of a radionuclide that would (without contributions from any other radionuclides) give rise to a peak impact equivalent to the appropriate regulatory criteria. These were then combined (as appropriate) to set limits on individual radionuclides or groups of radionuclides.

The Environment Agency considered that the radiological capacities derived in the 2002 Safety Cases, and re-assessed by BNFL in 2004 [28], were not sufficient to address regulatory requirements because:

- The radiological capacity calculations only addressed the vaults and did not take account of all of the wastes.
- The radiological capacity calculations did not take account of the effects of site termination events (coastal erosion, glaciation) or of exposures related to human intrusion or occupation of the site after physical erosion of the cap.
- The radiological capacity calculations did not adequately take into account the additive effects of the wide range of disposed radionuclides.
- The results of the underpinning assessments were not necessarily conservative and were not considered to provide an 'expectation value' of the risk associated with the environmental impacts that might arise as a result of releases from the entire LLWR.

Additional more specific points were also identified in the Environment Agency's Explanatory Document at the time of public consultation on its proposals for a revised authorisation for the site in 2005 [29]. These included issues relating to justification of performance measures, clarity of the methodology, the need to consider specific activity as well as total activity and issues relating to assessment timescales, exposed groups and parameter values.

Due to these concerns, the Environment Agency concluded that the 2002 Safety Cases and subsequent submissions did not provide a sufficiently robust basis for justification of the remaining radiological capacity of the site. The Environment Agency review led to continued authorisation of the site, based on the existing limits for waste disposal but only for disposals to Vault 8 [30]. For Vault 9, authorisation by the Environment Agency was stated to be dependent on both planning permission being given by Cumbria County Council and adequate information being provided to allow the radiological capacity of the site to be determined. This led to the identification of a range of requirements in Schedule 9 of the authorisation, including the need to present an updated ESC.

The Environment Agency's Explanatory Document also included an Appendix on *BPEO/BPM concepts and limit setting methodology*. In terms of setting limits it included some statements about methodology and the results of its review team for the 2002 Safety Cases [31] and supporting work [32]. The review noted two main approaches used for setting authorisation conditions based on an ESC:

- Set conditions based on ESC assumptions. This applies to waste engineering and design issues. These conditions require the operator to fulfil plans assumed and assessed in the ESC.
- Set conditions by means of an optimisation process. This balances allowable disposals with calculated impact, optimising the balance by considering a range of possible inventories, waste forms and designs. The allowable disposals are equivalent to the radiological capacity, and the conditions are set in terms of disposal limits by radionuclide and WAC.

As noted by the 2002 Safety Case review team [31], these two approaches are often used in combination and this is the approach we have used to derive and underpin the derivation of radiological limits for the LLWR described in Section 6.

The key requirements for deriving limits for radionuclide quantities are also discussed by the Environment Agency [29]. These can be summarised as:

- Derivation and application of radiological capacity values.
- The use of performance measures, such as dose and risk, as a basis for deriving capacity values.
- Consideration of a range of assessment scenarios to derive appropriate capacities.
- Consideration of the appropriate timescales to consider in the impact cases that are used to derive capacity values.
- Consideration of uncertainties associated with the results, noting that the limits must not be seen as absolutely certain numbers.
- Capacity is best expressed in terms of total inventory, but with specific activity limits where necessary to ensure doses potentially received are tolerable.
- Screening of radionuclides should be based on both environmental and occupational safety considerations.
- Consideration of the Sum of Fractions methodology, as recommended by the International Atomic Energy Agency (IAEA), to account for additivity of the impacts from different radionuclides (discussed in Subsection 3.3). Grouping of radionuclides for the setting of limits would need to take into consideration the times at which each radionuclide contributes significantly to impacts.
- Consider the basis for setting authorised limits to be applied over certain time periods, for example annual limits and limits over longer timescales. It noted that annual limits might be unnecessarily restrictive in terms of controls on disposals and also that simple total site limits might lead to a high proportion of the allowable limits being disposed within a few years which might place too much reliance on current estimates of radiological capacities.

These findings have been appropriately considered in work throughout the ESC, and specifically throughout this document, in particular as summarised in Section 6, which concerns radiological limits.

We also note that the Sum of Fractions approach has been recently used by the Environment Agency as a basis for a Permit for the disposal of very low-level radioactive waste at the Lillyhall Site in West Cumbria [33]. For this, sets of limits have been derived for the total site, for each disposal unit and for each consignment based on the groundwater, human intrusion and gas pathways respectively [34].

3.3 International Context

The principal organisation for sharing of international experience in safety assessments of near-surface radioactive waste disposal facilities is the IAEA. It has published a range of documents on the design, operation and safety assessment of such facilities and the role and setting of WAC. The importance of setting WAC has been recognised by the IAEA for many years and early publications addressed the expected content of WAC [35,36]. Of particular note is its publication, in the IAEA

Safety Requirements series, on 'Near Surface Disposal of Radioactive Waste' [37]. This states the requirement for WAC:

'Conditions for the acceptance of waste for disposal in the repository shall be specified. These requirements shall either be generically specified by the regulatory body or developed by the operator on the basis of either generic studies or site specific safety assessments, with account taken of appropriate radiological criteria, the conditions of operation, the planned duration of active institutional controls and the required characteristics of natural and engineered systems. If waste acceptance requirements are developed by the operator, they shall be reviewed and approved by the regulatory body. The established requirements shall be made binding on the waste generators or consignors of waste to the repository.'

In another IAEA requirements document, on pre-disposal management of wastes [38], the IAEA notes:

'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 that 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 [37]. 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 taken into account when establishing WAC for low and intermediate waste disposal sites [37,39,40]. These are summarised in Table 3.1. 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 to 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 of WAC that are necessary to ensure environmental safety.

A principal component of WAC is the setting of radiological limits relating to the quantities and concentrations of radionuclides that can be disposed in a facility. The

results of safety assessments are typically utilised to support the derivation of such radiological limits [37]. An approach to setting limits on the total quantities and specific activity of radionuclides is set out by the IAEA [41], often referred to as the 'Sum of Fractions' methodology. The approach is based on derivation of values of radiological capacity for each assessment case¹ and for each radionuclide. As discussed in Subsection 3.2, the radiological capacity 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:

$$\sum_n \frac{I_n}{L_n} \leq 1$$

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

To ensure regulatory criteria are met:

- Total disposals to a facility must be such that the Sum of Fractions values for each assessment case, based on total inventory is less than one.
- Activity concentration levels, for example in each consignment, must be such that the Sum of Fractions values for each assessment case based on activity concentration are less than one.

Such an approach can be used for both operational and post-closure periods of a disposal facility, with sets of radiological capacity values derived for each assessment case. The IAEA notes that this approach is cautious as no account is taken of the likelihood that the dose contributions from different radionuclides will arise at different times. (The approach ensures that disposals do not exceed a value of one even based on the total time-independent sum of individual peak doses or risks. The full time-dependent assessment for the same disposals might show that, as individual radionuclide peak doses arise at different times, the peak combined dose or risk with time never exceeds the regulatory criterion.)

The derived radiological capacity values for different assessment cases then need to be considered in order to establish a set of radiological limits. These limits can be calculated by a conservative approach, based upon taking the most restrictive capacity values for each radionuclide from all the assessment cases, or by selecting a sub-set of cases that represent the most limiting cases. An example of the Sum of Fractions approach, for a single assessment case, is given in Figure 3.1. The IAEA report [41] gives detailed examples of application of this methodology for both trench and vault disposals concepts. The application of this approach to the LLWR is developed in Section 6.

¹ 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.

Table 3.1 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.

Figure 3.1 Example of the use of the Sum of Fractions methodology

This example is based on a simple inventory for a disposal facility for the four radionuclides given below plus additional radionuclides that have lesser impacts per unit quantity of activity disposed. Impacts have been assessed for the assessment case of leaching of activity giving doses to an exposure group based on agricultural use of the land adjacent to the facility. Based on the assessment results, radiological capacity values have been derived, that is 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^{-6} per year.

Application of the Sum of Fractions methodology is by 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.

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 value 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 value. The role of the value for other radionuclides is discussed further in Subsection 6.2.

The total Sum of Fractions value is 0.25, demonstrating that the sum of the impacts from these radionuclides is equivalent to about a quarter of the regulatory criterion, that is their combined impact is about 2.5×10^{-7} per year.

The IAEA has recently initiated a new project, the Practical Illustration and Use of the Safety Case Concept in the Management of Near-Surface Disposal (PRISM) [42]. This followed three previous projects (NSARS, ISAM and ASAM) on the subject of assessment of near-surface disposal facilities. The emphasis of this latest project has changed from safety assessment to questions of practical implementation and how near-surface radioactive waste disposal facilities can be managed using safety cases. The objective is to share experience and communicate good practice and a particular theme is waste acceptance criteria. We are participating in and where appropriate will draw on information from this project, which is expected to be complete by 2012.

In the broader international context, we consider it important to be aware of practices in other countries relating to how environmental safety cases are used to derive

WAC. We therefore set out to identify WAC for radioactive waste disposal facilities in other countries to establish how they relate to environmental safety considerations. We have found however that in practice there are few examples of publicly available information on WAC for facilities in other countries. This is evident from both our own searches and also evident from similar reviews [43,44]. Further, it is often the case that the basis and derivation of the WAC are not clear. This paucity of information on the relationship between safety cases and disposal limits was also found in the review carried out in 2004 for the Environment Agency [32].

Whilst we have not been able to obtain detailed information on the derivation of radiological limits from safety cases, it is clear that the Sum of Fractions approach is widely acknowledged as a preferred approach and has been used as a basis for setting radiological limits in a range of countries including France, Spain and the USA.

In terms of non-radiological WAC, those relating to engineering criteria in particular are likely to differ between facilities and countries dependent on the disposal concepts, waste form, containers and vault designs being implemented. In contrast it is to be expected that there is likely to be more commonality in terms of materials to be excluded or restricted. From the information that we have been able to obtain, including unpublished information from exchanges with our overseas counterparts, the topics addressed in WAC are similar to those identified by the IAEA, described above, and no additional issues have been identified. Some of the key aspects addressed in the WAC include stability and voidage requirements, encapsulation of ion exchange materials, container specifications and excluded or restricted materials such as explosives, pyrophoric materials, free liquids and complexing agents.

We recognise that each country will have its own approach and national regulations and that different disposal facilities and different waste types will have site or waste specific requirements. Nevertheless, we believe there is considerable value in being aware of and sharing good practice. We will continue to keep under review the practices in deriving WAC used in other countries, with emphasis on radioactive waste disposal facilities with broadly similar scope and scale to that of the LLWR.

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

Wastes consigned to the vaults are normally grouted in steel containers before emplacement. The wastes are, with some exceptions, either supercompacted pucks or non-compactable materials such as soil, concrete and bulk metallic items. Certain materials are required to be absorbed or encapsulated prior to disposal. On occasions, very large items of waste that it is not practicable to size reduce are disposed directly in the vault and grouted in place.

The objective of the analyses presented in this section is to identify potential requirements that are relevant to environmental safety from the perspective of the waste form and the physical composition of the wastes. These aspects are important because they are relevant to optimisation of the performance of the disposal system and because they influence the rate of release of radionuclides or non-radiological contaminants into the environment.

Important issues for consideration include the container, the waste form, additional requirements for specific types of wastes and controls in relation the performance of the cap. Each of these is considered below.

4.1 Containers and Waste Containment

A fundamental concept within regulatory guidance is that of optimisation of the disposal system and associated waste forms such that impacts are ALARA (GRA Requirement R8 [18]). This is reinforced by our Permit, which requires best available techniques (BAT) to be used to minimise the activity of gaseous and aqueous discharges to the environment (Schedule 1) [21].

The '*Optimisation and Development Plan*' report [10] describes how the LLWR system and plans for its development have been optimised. There is a continuing requirement to show that the facility is managed consistent with the principles of optimisation. LLWR will continue to demonstrate BAT, and therefore ALARA, in future operational approaches and associated decision making. Appropriate WAC and associated controls are required to ensure that the waste form and containment required to deliver optimisation are recognised and implemented. Requirements for containment are currently met by a range of controls, described below.

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. These ensure safe handling of the wastes during all phases from the point of waste generation to emplacement in the vault. It is noted that 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 (paragraph L3.1) [20]. Wastes that cannot be readily consigned in the specified approved containers may be accepted in other containers, but only on approval prior to use. Non-containerised wastes are also accepted for disposal at the LLWR but are assessed on a case-by-case basis. Examples of such wastes include redundant fuel flasks and redundant reactor heat exchangers. All such approvals take into consideration operational requirements, both for emplacement of the wastes and conventional and radiological safety aspects, and potential release to the environment. Due consideration is also given to the effect of the stacked containers

on the vault base slab and associated drainage systems. These include the effect of higher stack levels within the vaults, as assumed in the ESC [1].

We are carrying out work to consider alternatives to the current standard disposal containers [45,46]. The objectives of this work are to consider options that maximise utilisation of the vault volume capacity and at the same time reduce the amount of grout required to fill voidage within consignments and therefore overall costs of disposals. A range of new, innovative packaging solutions is being considered, including the potential use of re-usable transport containers with inner disposal liners. The latter are being designed to minimise void space, both internal and external. Disposal of loose waste directly into discrete cells within a vault is also an option being evaluated.

These potential new options are not part of the assumed basis of the ESC. However we are committed to ensuring that all new packaging innovations will be the subject of consultation with customers, regulators and stakeholders and that the short and long-term environmental impacts will be fully assessed to underpin any future options assessment concerning containers. The principle of demonstrating ALARA will be key throughout.

As well as container specification and selection, it is important to identify and consider other factors that might influence containment and release of radionuclides or other contaminants. In terms of container integrity and minimisation of releases in the shorter-term, it is important that substances that might lead to rates of corrosion of the containers sufficiently significant to challenge the assumptions underpinning demonstration of environmental safety are excluded or treated to be made safe. In this respect, the current WAC exclude strong oxidising agents (paragraph L1.9, see Table 8.2) [20]. It is considered this should be strengthened by adding a requirement to exclude materials that could lead to significant corrosion of containers within the lifetime otherwise expected for such containers.

Other current restrictions that are protective of container integrity are those on reactive substances (paragraph L1.5) exclusion of explosive materials (paragraph L1.6), flammable liquids (Paragraph L1.7) and pressurised gas receptacles and aerosols (paragraph L1.10). It is noted that all these current WAC are also requirements of the Permit for disposals [21]. Whilst all these aspects are necessary for operational considerations, it is considered that they are also required for containment.

The current WAC [20] already include requirements to exclude free liquids (paragraph L1.7) and soluble solids (paragraph L1.8) that could potentially give rise to release over short periods. We have identified that materials in the form of powders or other fine granular materials, including incinerator ash, should also be subject to some restriction. In the context of containerisation, 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. We consider WAC relating to powders further in Subsections 4.3, 4.4 and 5.7.

Also of relevance is the current WAC requirement that non-fixed contamination levels on disposal containers must be as low as reasonably practicable and in any case not more than 0.4 Bq cm^{-2} for all alpha emitting radionuclides and 4 Bq cm^{-2} for all other radionuclides (averaged over an area of 300 cm^2) (see paragraph L2.5) [20]. This is derived from Transport Regulations requirements 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.

WAC provide the principal means by which the required level of waste containment is specified for continuing disposals. In order to ensure that the implications of changes in waste management practices, by consignors or by LLWR, are understood and assessed, review arrangements will be established within LLWR to ensure that no potentially significant changes are introduced without further consideration of the implications for environmental safety. Implementation requirements are discussed further in Subsection 8.1.

4.2 Grouted Waste Form

As described in the '*Optimisation and Development Plan*' report [10], the grouted waste form was primarily introduced, in the late 1980s, to minimise voidage in order to protect the performance of the cap. An assumption within the 2011 ESC is that wastes will continue to be grouted prior to disposal.

An understanding of the evolution of such grouted wastes and the influence of the grout on conditions in the vaults has been developed for the ESC, based upon a number of sources and in particular the outcomes of detailed biogeochemical modelling [6,47]. This has shown that the grout provides additional functions that are relevant to safety. In particular:

- It is anticipated that reducing, alkaline conditions will be established in the vaults for a period of thousands of years, and the grout contributes significantly to this. Such conditions will maximise retention within the vaults of certain species, for example uranium will be solubility limited under these conditions and the vault conditions will also stabilise the Tc(IV) oxidation state.
- The cement grout will also provide a good sorbant for other metal contaminants.
- Modelling studies indicate that carbonation (which involves trapping of carbon in carbonate as a result of interaction with the grout) may mean that about half of the inventory of C-14 will be incorporated in the cement grout through the process of carbonation and hence will not be available for release from the near field.

Studies have explored the implications of different assumptions inherent in the modelling approach, including representation of heterogeneity and homogeneity, different proportions of grout in future disposals, and the potential application of different waste treatment options in the future [6,47]. Some key outcomes of the sensitivity studies are:

- High pH conditions within the vaults are likely to be maintained even if there are reductions to the proportions of grout in future disposals compared to current projections. Reducing the grout content by 50% had no significant effect on the pH, which was maintained close to pH 11 as in the reference case.
- Reductions to 10% of the current proportion of grout would have a more significant effect, but still the pH would be buffered to about 10 by anaerobic corrosion for a period of 1000 or more years, and uranium would still be solubility limited (albeit at slightly higher concentrations compared to pH 11).
- Reducing the cement grout by 50% compared to current projections would, overall, have a negligible effect on C-14 release from the total inventory.

The implications of the above are that whilst the grout provides important safety functions in addition to void-filling, the system is not very sensitive to the proportion of

grout in wastes. On this basis, WAC on the quantities of grout are not considered necessary.

Nevertheless, it is possible that at some point in the future there may be potentially significant changes in waste treatment practices either by consignors or changes by LLWR. In order to ensure that the implications of any such changes are assessed, review arrangements will be established within LLWR to ensure that no potentially significant changes in waste form are introduced without further assessment of the implications for environmental safety. This is discussed further in Subsection 8.1.

In particular, as discussed in Subsection 4.1, we are considering alternative options for waste packaging as part of the UK approach to optimisation of LLW management practices [45,46], including the potential use of re-usable transport containers with inner disposal liners and potentially disposal of loose waste directly into discrete cells within a vault. Such practices would result in less metal and grout being present in the vaults. These may lead to changes in the evolution of the near field that may be significant in terms of the safety functions described above. In particular, a reduction in grout content of greater than 50% compared to present projections could have implications for C-14 release. Any such packaging innovations will be the subject of further assessment and consultation before their introduction, in order to ensure any changes to the current practices are fully assessed.

4.3 Consideration of Specific 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. Potential requirements for controls are considered below.

Free liquids are excluded from wastes by existing controls. Nevertheless, it is desirable for waste management purposes to retain the ability to accept wastes with minor quantities of absorbed liquid wastes provided that they are not released subsequent to disposal. The current WAC (paragraph L1.7, see Table 8.2) 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^{-2} [20]. This was derived as part of the waste form development work in the early 1990s [48]. The criterion is consistent with:

- 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 has been introduced and the 2011 ESC considers higher stacking within the vaults to up to nine standard half-height containers [5]. Revised designs for the final closure cap have also been developed [5]. Therefore it is important to review the basis for ensuring retention of absorbed liquids if present in disposed wastes.

Review work has shown, based on the maximum standard container weight limit of 42 t and the cap design assumed in the ESC [5], that maximum applied loads at the base of any stack will not exceed 340 kN m^{-2} in any vault [49]. To enable the overall objective of retention of absorbed liquids to be met, we will therefore conservatively retain the current WAC based on an applied load of 400 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.

The current WAC for the LLWR require soluble salts and ion exchange materials to be conditioned in a suitable solid matrix and that the method must be approved by LLWR prior to disposal (paragraphs L1.8 and L1.13) [20]. The treatment 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 as the containers degrade and are infiltrated by water. 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).

Consideration has also been given as to whether any other waste types could give rise to similar short-term releases. We have identified (Subsection 4.1) that powders, including the finer grain sizes of incinerator ash, could under certain circumstances give rise to enhanced release. Conditioning of powders is also considered beneficial in terms of maintaining cap performance (Subsection 4.4) and is also a consideration in terms of potential for enhanced contaminant transport in groundwater (Subsection 5.7). We therefore consider that powders should be conditioned to ensure their long-term retention prior to being consigned. (Powders will be defined in revised WAC but a preliminary definition is that powders comprise solid particles with diameters of less than 1 mm.) For this purpose, incinerator ash is regarded as a powder. We have not identified any other waste materials with this potential for short-term release.

4.4 Waste Degradation and Cap Performance

It is planned that a substantial engineered cap will be implemented over the trenches and vaults prior to closure [5]. The role of the cap in limiting infiltration into the wastes and hence the volume of leachate that is generated is of key importance.

Projections of future cap performance rely in part on assumptions regarding the potential for differential settlements within the wastes. Differential settlement could occur when there are significant differences in the voidage and degradation properties of wastes within the vaults. A key requirement is therefore to set controls that ensure compliance with the requirements necessary for the long-term performance of the cap.

The need to minimise differences in voidage in disposed wastes was an important consideration for the introduction of the revised waste form when the change from trench to vault operations began in the early 1990s [10]. A grout facility at the LLWR was brought in to operation as part of this revised disposal strategy. The main benefit of the grouting process is that it serves to eliminate the great majority of voidage within containers. The only residual voidage at the time of waste emplacement is that in isolated parts of the waste to which the very fluid grout cannot penetrate and that in the minor spaces between containers.

In work for the 2011 ESC concerning the potential for cap settlement [50], the following issues have been identified as requiring consideration.

- The void space between containers, and voids associated with the structure of the containers that are not filled with grout.

- Inaccessible voidage within the waste at the time of waste emplacement.
- Voidage created by waste degradation.

Each of these is discussed below.

4.4.1 Voidage between Containers and Within Container Structures

Where void spaces between container stacks are significant post-emplacement, these 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 within the inside of 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 [50]. This voidage is however relatively uniformly located across the vaults and is unlikely to have a significant effect on cap performance. In addition, 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 [50].

4.4.2 Inaccessible Voidage Within the Waste

In terms of inaccessible voidage at the time of waste emplacement, the WAC for the LLWR define this as '*the voidage within a disposal container, including within the waste, which will not be readily penetrated by grout during the conditioning process prior to disposal at the LLWR.*' The current WAC include the requirement that inaccessible voidage is minimised as far as reasonably practicable and must not exceed 10% of the internal volume of the disposal container (paragraph L3.4) [20]. It also requires that as far as reasonably practicable, any inaccessible voidage should be uniformly distributed within the container.

In the late 1990s a study was carried out to investigate the inaccessible voidage within wastes of different types of material [51]. A range of waste types was loaded into segmented parts of a container, which was then grouted. The container was then cut into various sections to show the effects of grouting and any residual voidage. The results showed residual voidage after grouting for the different waste forms is very limited, about 1% or less by volume. Higher levels are only expected to occur if there are specific reasons, for example the presence of asbestos wastes that are not supercompacted and which the WAC require the associated voidage to be specifically accounted for as inaccessible voidage (paragraph L1.16.2) [20].

Whilst the majority of waste consignments are therefore expected to have minimal voidage after grouting, we consider that inaccessible voidage should continue to be limited. This is discussed further in the next subsection.

4.4.3 Voidage Created by Waste Degradation

Potential voidage that may be created by waste degradation is also of potential significance. The effects of inaccessible voidage and voidage formed by waste degradation are considered additive in terms of their effect on cap performance. A single limit has therefore been derived [50], as shown below, for the total acceptable voidage, including inaccessible voidage and that due to waste degradation. In addition to revised WAC, consignment documentation will be modified to require levels of inaccessible voidage to be recorded if greater than an assumed de minimis

level of 1%. This will enable total potential differential settlements to be limited. It will also aid future design and assessment work.

Consideration has been given to the different volume changes that may arise due to future degradation of the various types of materials present in the wastes [50]. For soil, rubble and concrete type wastes, and for the grout itself, no significant volume changes are expected. For metallic wastes the volume will increase due to the formation of corrosion products, and is discussed further below. For most other waste types, for example plastics and inorganic materials, but with the important exception of biodegradable materials, only small volume changes are expected. Volume changes for these materials are expected to take place slowly compared with the time period of up to 1000 years for which for which the ESC assumes the cap acts as a low permeability barrier.

In contrast biodegradable materials, typically comprised of paper, cardboard and wood², are more significant. It is estimated from near field modelling work that about 90% of the volume of biodegradable materials in the vaults will be lost due to waste degradation [52]. It has been concluded therefore that to limit differential cap settlement, control of the biodegradable content of wastes is required.

The work on cap performance has concluded that controls should be established to limit differential settlements within the key component layers of the cap to 500 mm in order not to have a detrimental effect on its performance [50]. This work shows that the effect of voidage within the wastes decreases with depth below the cap due to the structural characteristics of the cap and by the entraining of wastes from adjacent stacks, as shown in Figure 4.1.

This shows that, for stacking of nine half-height ISO containers, the permissible voidage is 20%. This must take into account both inaccessible voidage at the time of disposal and the long-term voidage formed by degradation of biodegradable materials. For example this might be 5% inaccessible voidage and 15% biodegradable materials (strictly 16.6% if the 10% residual material volume after waste degradation is allowed for).

For lower stack heights planned for some areas of the vaults, the 500 mm differential settlement criterion can be met with higher levels of voidage [50]. For example, for four half-height ISO containers in a stack the permissible voidage increases to 35%. Consignments of potential voidage in excess of 20% may therefore be acceptable provided that they are placed in areas of the vault with lower stack heights. Alternatively, they could be emplaced in any stack provided that total stack voidage conditions are complied with (and noting that this is not a simple average, as noted above).

The appropriate voidage criterion therefore varies from 20 to 35% dependent on stack height (and location within the stack). We will assess, and discuss with consignors, the implications and most appropriate practicable basis for setting specific values. This will also take into consideration the extent to which a practicable emplacement strategy can be used to limit the effects of voidage. Our considerations in setting WAC relating to voidage and cap settlement will take into account both inaccessible voidage and that formed by degradation of biodegradable materials. The resulting controls will be used to ensure that consignments with high biodegradable content are only accepted based on submission of a Waste

² Biodegradable materials will be defined in revised WAC but a preliminary definition is paper, cardboard, cotton, wood, putrescible materials, other cellulosic substances and materials that degrade to create significant voidage compared with their as disposed volume. In this context voidage is assumed to be significant if in total the potential voidage exceeds 1% of the internal volume of the disposal container.

Consignment Variation Form, assessment by LLWR against the settlement criteria [50] and management as part of the waste emplacement strategies discussed in Subsection 8.3. The fraction of wastes with a biodegradable fraction exceeding 20% is estimated to be about 10% [53].

For Vault 8, the cap settlement work has identified that in some areas of the vault the quantities of biodegradable wastes already emplaced means that additional consideration needs to be given to potential voidage levels and the implications for acceptable levels of biodegradable materials in future wastes [50]. For these areas, specific controls will be developed to ensure consistency with the above voidage objectives.

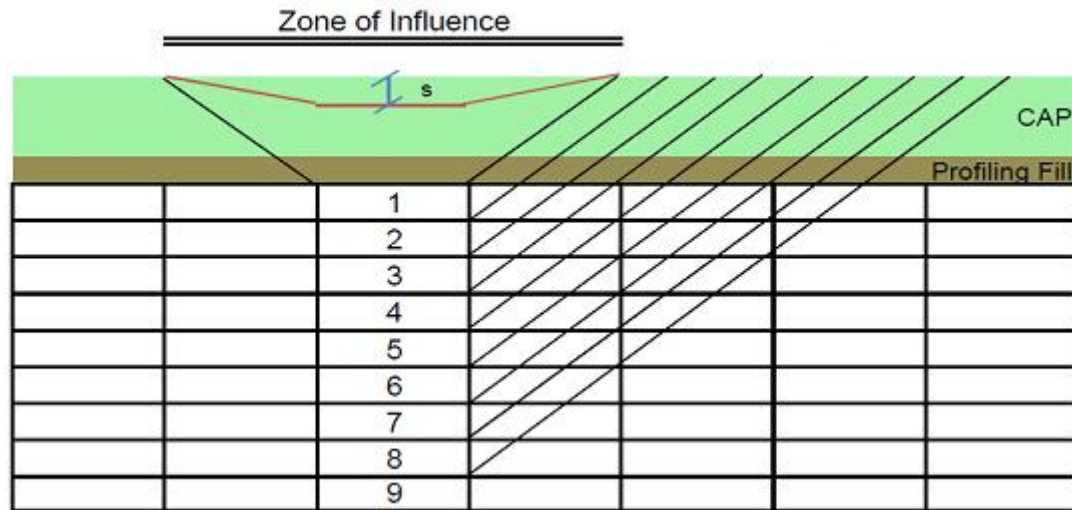


Figure 4.1 Illustration of cap settlement to comply with 500 mm cap settlement criterion

Row No.	ISO Width (m)	ISO Height (m)	HHISO Settlement (mm)	Zone of influence (m)	Settlement at surface (mm)	Cumulative settlement (mm)
1	2.4	1.36	244.8	5.12	92	92
2	2.4	1.36	244.8	7.84	76	168
3	2.4	1.36	244.8	10.56	64	232
4	2.4	1.36	244.8	13.28	56	288
5	2.4	1.36	244.8	16.00	50	338
6	2.4	1.36	244.8	18.72	45	382
7	2.4	1.36	244.8	21.44	40	422
8	2.4	1.36	244.8	24.13	37	459
9	2.4	1.36	244.8	26.88	34	493

Table 4.1 Cap settlement values to comply with the 500 mm cap settlement criterion

The cap settlement work has also identified that corrosion of metals may lead to expansion such that in stacks with high metal content there could potentially be significant heave within the cap [50]. Whilst this is not certain, a cautious approach may be required in order to reduce the effect of potential expansion for those consignments with metal in excess of 25% by volume. In such cases, due consideration will be given to the offsetting factors from volume changes in other wastes in the same stacks. It is noted however that such high metal contents in wastes result in very heavy consignments. Such consignments are infrequent and this is expected to remain the case. We expect that such wastes can be managed solely within an emplacement strategy and that a specific WAC for metal content is not required.

In terms of the current WAC for the LLWR, the principal requirements on the physical composition of wastes concern controls to exclude or limit certain materials on operational and environmental safety considerations (Section L1) [20]. There is also the requirement that reasonable means must be used to limit the quantity of putrescible materials and that such materials must not exceed 1% by weight (paragraph L1.15) [20].

The 1% criterion was partly based on such an amount being relatively small in comparison with the 10% inaccessible voidage criterion. Putrescible materials are defined as materials liable to be readily decomposed by micro-organisms excluding wood and paper. Such materials are liable to degrade significantly quicker than materials such as paper and wood. We do not, however, consider that this is of any different significance, in terms of cap performance, to other biodegradable materials. Revised WAC will therefore be set so as to include consideration of putrescible materials as a component of biodegradable materials. Putrescible materials are discussed further in Subsection 5.2 in terms of potential effects of degradation products on the release characteristics of contaminants.

The potential for loss of soluble materials and fine grain materials from consignments due to washout by infiltrating water also requires consideration. Soluble solids (as discussed in Subsection 4.3) are currently excluded from disposal without being fixed in a solid matrix (paragraph L1.8) [20] and we intend to retain this condition, partly to assist in minimisation of voidage. In terms of fine-grained materials such as powders that might under adverse circumstances be preferentially released, as discussed in Subsection 4.3 we propose these should be conditioned prior to being consigned to ensure their longer-term retention. We conclude that with the adoption of these measures, washout of materials is not expected to give rise to additional waste settlement.

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5 Biogeochemical Properties of Wastes

The objective of the work described in this section is to identify potential waste components, or their degradation products, that could adversely influence release of radionuclides or non-radiological contaminants and therefore increase impacts. Relevant materials have been assessed in terms of their potential to influence the evolution of biogeochemical conditions within the LLWR.

A study undertaken for the 2011 ESC considers both the potential for enhanced release of radionuclides and non-radiological contaminants from wastes and the potential for enhanced mobility within the near field and the geosphere, and any implications for environmental safety [54]. Assessments of the sensitivity of the process system and potential implications have then been used to inform the identification and development of appropriate WAC.

To determine the materials of potential significance, the full list of material types in WIDRAM 09 [55] and the United Kingdom Radioactive Waste Inventory' (UKRWI) [56] were reviewed. This information, together with broader considerations of biogeochemical properties, was used to identify major or minor constituents of waste materials or other chemical species that are of potential significance [54]. The review was based on an understanding of factors relevant to release derived from development of the near field conceptual model and underpinning detailed computational calculations. The results of the environmental monitoring programme [57,58] were also reviewed to establish whether any additional substances or species might be of potential significance.

The following materials were identified as candidates for more detailed study as a result of these reviews:

- Cellulosic materials;
- Putrescibles;
- Non-cellulosic polymers;
- Ion exchange materials;
- Superplasticisers;
- Complexing agents;
- Other materials such as oils, powders, sulphates and nitrates.

These are discussed in turn below, summarising the main outcomes of the analyses presented in reference [54].

5.1 Cellulosic Materials

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

The alkaline degradation of cellulose and the identification of the resulting degradation products have been studied extensively, through both experimental work and supporting modelling. Cellulose has the potential, through mechanisms such as alkaline hydrolysis, to generate degradation products, such as isosaccharinic acid, which have strong complexing ability and can significantly enhance the mobility of radionuclides and non-radiological contaminants. However, experiments that considered cellulosic waste with LLWR grout indicated that isosaccharinic acid did not form and no increase in contaminant solubility was recorded [59]. The implication

is that cellulose degradation within the LLWR vaults does not proceed by alkaline hydrolysis reactions and, if any isosaccharinic acid were to be produced, it would quickly be degraded by microbial processes [60].

Microbial degradation results in the production of landfill gas and short chain volatile fatty acids, such as acetate; these have a lesser effect than isosaccharinic acid on radionuclide mobility. These reactions have been included within the biogeochemical modelling and underpinning calculations of the ESC [6]. Such studies have shown that acetate may influence uranium, technetium and thorium speciation but only under the more acidic conditions encountered in the trenches.

Assessment work has shown that the fraction of C-14 released as a gas is dependent on the form of the waste that contains the C-14 and the nature and volumes of materials present in the surrounding areas of the vaults. This is discussed in Subsection 6.3.3 and more fully in other parts of the ESC and supporting reports [12,52,66]. It has been concluded that control of wastes forms associated with C-14 disposals may be required and this will be considered further by LLWR.

In summary, it is considered likely that cellulose degradation in the LLWR vaults will proceed through microbial routes; and there is strong evidence to suggest that such degradation will not significantly influence the release and mobility of relevant contaminants under vault conditions. The exception is for waste forms associated with significant levels of C-14 disposals. No requirement has therefore been identified for WAC to limit the cellulosic content of the majority of wastes, but specific consideration will be given to waste form controls, and associated emplacement restrictions, for wastes with significant levels of C-14.

5.2 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 current WAC for the LLWR to not exceed 1% by weight (paragraph L1.15) [20].

It is considered that disposals of putrescible materials do not present an issue for LLWR in terms of their degradation products and the potential for enhanced release. Similar degradation products are produced as for cellulose degradation, and so the same arguments apply [54].

Gas production also requires consideration, as production rates for putrescible wastes will be high and will promote the production of methane, which could increase the mobility of associated C-14. However, the inventory of putrescible materials is comparatively low. In addition the high rate of degradation of putrescible waste will mean that the greatest potential effect will be during the PoA phase. Calculated doses for gaseous C-14 for this phase are low, even with very pessimistic assumptions [64]. Therefore the implications of any variations to release assumptions are expected to be small. It is concluded that any increase in C-14 production due to the degradation of putrescible waste will have minimal effect on the overall impacts from gaseous C-14.

Whilst we have not identified a requirement to limit putrescible materials in terms of environmental safety, there may be operational safety implications in terms of human health and gas generation that need to be assessed. At the present time therefore no change is considered necessary to the current limit of 1% by weight for putrescible materials.

5.3 Polymeric Materials

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. Some of these materials have the potential to degrade and produce products that significantly complex with radionuclides and non-radiological contaminants. However, analysis of the likely degradation rates of relevant materials indicates related processes will be slow [61] and unlikely to generate sufficient quantities of degradation products to significantly affect contaminant mobility at LLWR. This conclusion is supported by experimental studies [54].

Based on the discussions above, there is no reason to limit the disposal of these materials to the LLWR.

5.4 Ion Exchange Materials

The majority of the ion exchange materials likely to be disposed of at the LLWR is in the form of organic, 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 [54].

It has therefore been concluded that the current WAC requirement (paragraph L1.13) [20] to fix ion exchange materials in a solid matrix prior to disposal should continue for the reasons discussed in Subsection 4.3, and that no additional requirements are necessary.

5.5 Superplasticisers

Superplasticisers comprise organic substances added to cement to improve its rheological properties, in particular to provide good grout penetration throughout wastes during grouting. At the LLWR, Sikament 10, a vinyl co-polymer based superplasticiser, is used at concentrations of about 0.9%. Superplasticisers are also likely to be present within disposed concrete and cements.

Superplasticisers have been identified as a potential source of complexing agents and experimental studies provide evidence that superplasticisers can significantly enhance radionuclide mobility. However, these experiments have all been carried out with the superplasticiser in free solution. In practice, the LLWR superplasticiser is intimately associated with the cement matrix and it is considered the majority of it will only be available for leaching as the grout matrix itself degrades. Leaching from the cement matrix is expected to be slow and released concentrations are not expected to be of significance [54].

Overall, it has been concluded that superplasticiser is unlikely to be released into porewater at high enough rates or concentrations to adversely affect radionuclide behaviour. This also applies to any superplasticiser present in concrete or cement wastes that might be disposed as LLW to the LLWR. Therefore no requirement has been identified to place limits on the disposal of concrete or cement waste that might contain superplasticisers.

5.6 Complexing Agents

Complexing agents have the potential to significantly enhance radionuclide and non-radiological contaminant mobility, even at low concentrations. The Permit for disposal of wastes at the LLWR requires chemical complexing or chelating agents to be excluded (Schedule 6, Clause 2 (b) (vii)) [21].

Complexing agents (in the context of LLW) will generally be associated with decontamination or decommissioning waste streams. In particular, decontamination agents are used to clean material by removal of radionuclides from surfaces. The two broad categories of complexing agents within future LLWR waste streams are:

- Aminopolycarboxylic acids – including ethylene diamine tetraacetic acid (EDTA), nitrilo triacetic acid (NTA) and diethylene triamene pentaacetic acid (DTPA).
- Polycarboxylic acids – including citric and oxalic acids.

Of these, aminopolycarboxylic acids are of particular significance because they can increase the mobility of radionuclides by several orders of magnitude and are not expected to degrade quickly in the repository near field [54].

Species such as citrate and oxalate polycarboxylic acids have lesser effect as complexants and are likely to have a shorter lifetime due to microbial degradation [54]. In addition, work on the potential for boron (used in the nuclear industry due to its neutron absorption properties) to act as a complexant, if present as borate, has been reviewed. The review, supported by thermodynamic modelling studies, concluded that the presence of borate has no significant effect on radionuclide mobility at the LLWR [54].

It has been concluded that the presence of aminopolycarboxylic acids in wastes for disposal at the LLWR should be excluded. Alternative biodegradable complexing agents should be used in decontamination processes that lead to wastes for disposal to the LLWR. If aminopolycarboxylic acids are present in LLW, then appropriate treatment (for example immobilisation, or chemical or thermal degradation) must be carried out prior to disposal at the LLWR.

The presence of materials containing other complexing agents such as polycarboxylic acids should also be minimised, but evidence suggests that levels below 0.1% by weight are not expected to lead to any significant effect [54].

The current WAC that chemical complexing and chelating agents must be excluded (paragraph L1.12) [20] must be retained until our Permit changes. We will, however, discuss this aspect with the Environment Agency with the objective of implementing an approach to waste acceptance that recognises complexants of particular types in terms of their effect on radionuclide mobility and persistence, excluding those containing aminopolycarboxylic acids while limiting others by weight. This could be supported by guidance that includes consideration of a range of potential complexants that might be used in the nuclear industry and elsewhere. We consider that this would provide an improved understanding of the requirements for control of complexants in LLW.

5.7 Other Materials

This UKRWI category 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 (paragraph L1.7) [20]. This is partly a requirement to ensure compliance with

the discharge Consent for the site that requires the discharges to be free of visible oil or grease [62]. 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 higher than groundwater.

The evidence for any negative effect on the biogeochemical evolution of the LLWR is, however, only suggestive. 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 make a major effect on travel times from the LLWR through the geosphere and microbial degradation is likely to reduce any effect of NAPLs [54].

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

Consideration has also been given to the potential for powders and other colloid forming wastes to enhance radionuclide mobility. This might occur by means of sorption of radionuclides onto particulates and mobile colloids and transportation in groundwater without retardation. However, studies of 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 [63]. A similar conclusion has also been drawn in terms of the potential influence of particulates and colloids within the vaults, provided that concentrations greater than five percent by weight in porewater do not occur [54]. Given this relatively high threshold concentration level, enhanced mobility is not expected to be an issue other than potentially for wastes predominantly in the form of powders. Consideration will therefore be given to this in terms of setting WAC relating to powders.

Of the remaining substances that are relevant to the 'other materials' category in the UKRWI, it is noted that 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 particular, their presence may delay the development of methanogenic conditions and, in the case of nitrate, potentially lead to the re-oxidation of the site.

On the basis of analyses of the geochemical reactions and process involved, however, it is considered that the effect of these substances will be minimal [54]. Any additional nitrate within the waste will be effectively consumed by the degradation of cellulose and corrosion of waste metal. The presence of sulphate in the waste may actually be beneficial through assisting in the development of sulphate reducing conditions and promoting an anaerobic environment, which will reduce the mobility of redox sensitive radionuclides. Additionally, sulphate reduction may occur through the oxidation of organic carbon, thus increasing the formation of carbonate species and reducing the generation of methane.

We have concluded that there is no requirement to specify WAC to limit the disposals of either nitrate or sulphate.

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6 Controls to Limit Radiological Inventory

Our approach to setting radiological limits is based on derivation of radiological capacities and the Sum of Fractions methodology, with the exception of limits for low-activity sources and fissile radionuclides (discussed in Subsections 6.5 and 6.6 respectively). The Sum of Fraction methodology is described in Subsection 3.3, which includes an illustration of its use.

As described in Subsection 3.2, radiological capacity values are the quantity of activity for each radionuclide (without considering any other radionuclides) which would give rise to a peak impact equivalent to the appropriate regulatory criteria. In order that the combined impacts of all radionuclides are considered when setting radiological limits a 'Sum of Fractions' methodology is used such that:

$$\sum_n \frac{I_n}{L_n} \leq 1$$

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

Radiological capacity values are given in terms of total activities (TBq) or activity concentrations (GBq t⁻¹). For radionuclides that decay to unstable isotopes, radiological capacity values are based on the quantity of disposed activity including the summed impacts of the parent and all daughter radionuclides.

Radiological capacity values can be derived for an appropriate range of assessment cases. The capacity values are derived based on the assessment results for the time of peak assessed impact for each radionuclide. These are expressed in terms of potential annual doses to a member of an appropriate critical group for impacts during the PoA or a Potential Exposure Group (PEG) for long-term impacts. Peak impacts from different radionuclides may occur at different times (for example, due to differential 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.

The application of this methodology in terms of deriving radiological capacities and potential limits is shown in Subsections 6.3 and 6.4. Firstly, however, consideration is given to the approaches adopted to 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).

6.1 Selection of Assessment Cases

The first stage 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.

The assessment calculations consider potential impacts that may occur both during the PoA [11] and thereafter [12]. For each of these, a range of assessment cases is considered in terms of different release and exposure pathways and for different times of potential exposures corresponding to different site evolutions or different times of human intrusion. The ESC also considers doses to non-human biota [14]

but it is considered that these are not an appropriate basis for setting WAC. The selection of assessment cases is discussed further below.

For each of the selected assessment cases, the relevant regulatory criterion also needs to be identified. These are based on the criteria given in the GRA [18] with supplementary regulatory guidance as noted below:

For the PoA, the relevant criteria are:

- 0.3 mSv per year dose constraint from any source, and
- the additional limit of 20 μ Sv per year for groundwater pathways [22].

After the PoA, the principal criteria used are:

- the risk guidance level of 10^{-6} per year; and
- the dose guidance levels for human intrusion of 3 mSv per year for exposures continuing over a period of years and 20 mSv per year for short-term exposure.

These are taken to apply to all the LLW disposal facilities at the site, including the summed impact of disposals to the trenches and vaults.

We consider that the relevant cases for consideration in establishing limits are those assessment cases that are the most representative of each pathway and critical group or PEG relevant to that pathway. It is considered unreasonable to derive limits on the basis of assessment cases that are unlikely to occur, even though such cases might be explored within the assessments. This is consistent with the findings of the work carried out for the Environment Agency at the time of the review of the 2002 ESC [32] which notes that *'it is questionable whether quantitative limits should be established on the basis of some of the less likely but high consequence scenarios that it might be necessary to consider in safety cases. The recognition that it may be appropriate to base quantitative disposal limits on a different set of scenarios than is considered in the post-closure and operational safety cases is an important step.'* The approach here is therefore to base the selection of cases on the reference case assessment results for each pathway.

The reference case results represent either the 'most likely' or a central set of results from the assessment cases. This approach is consistent with the GRA for the phase after the PoA in that the criteria are guidance levels and not absolute limits. This reflects that there is recognition that there are uncertainties in such assessments and that some assessment cases will be identified to explore uncertainties and to illustrate 'what if' situations to test the robustness of the safety case.

Discussion of the uncertainties in the assessment cases and the basis for the cases taken for deriving the radiological capacity values is given in the respective assessment reports [64,65,66,67,68,69] and the Level 2 reports [11,12].

Having identified the appropriate assessment cases, radiological capacity values 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^{-1}). We have identified limits that we will apply to:

- Total activity levels at the scale of the vaults or the site.

- Waste consignments.

In deriving total activity limits, consideration has also been given as to how best to address the impacts from disposals to the trenches, past disposals to Vault 8 and future disposals to Vault 8 to 14. Firstly, in terms of the vaults, it is considered that it is appropriate to set limits for the vaults as a group, representing 'current and future disposals', including the existing disposals to Vault 8. Inclusion of disposals to date to Vault 8 is appropriate given the ongoing nature of operations in the vault and that such disposals are of a broadly similar waste form to future disposals. (They are also very different to the waste forms in the trenches that are more appropriately managed separately as 'historical disposals'). Consideration is also given as to whether limits on total activity 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.

Secondly, 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 can be considered to be independent of each other. For those cases for which trench and vault impacts are additive, the derivation of limits for vault disposals needs to take account of the disposals to the trenches and their impacts.

6.1.1 Period of Authorisation Cases

For the PoA, doses are assessed for gaseous releases, releases in leachate to the marine environment (by the Marine Pipeline), to surface water systems and to groundwater, and from external radiation [64]. The appropriate regulatory criterion is the 0.3 mSv per year dose constraint from any source, with the additional limit of 20 μ Sv per year for groundwater pathways.

For gaseous releases, doses from H-3, C-14 and Rn-222 (from disposed Ra-226) are assessed by assuming releases from the site are then subject to transport and dispersion in the atmosphere and, for H-3 and C-14, uptake by crops grown on adjacent farmland [64]. Appropriate critical groups have been defined that may receive doses from inhalation and by consumption of foodstuffs. These impacts are determined by the total inventory, rather than activity concentrations on a consignment basis, and by the releases from the trenches and vaults in total. In setting vault disposal limits consideration therefore needs to be given to the impact from disposals to the trenches. It is considered that this assessment case is appropriately used to derive radiological capacity values on the scale of the vaults as a group. The potential additive impact for external radiation also needs to be considered and is discussed further below.

Liquid effluent releases are also assessed in the PoA assessment. The assessed peak future dose from the site is 0.83 μ Sv per year [64]. For the vaults, releases in leachate discharged to the Marine Pipeline are very conservatively estimated assuming the release of radionuclides is directly proportional to those from the trenches. In practice, containerisation of wastes disposed of to the vaults, although not necessarily 100% effective over the full length of the PoA, will ensure that the impact from vault disposals is very small, both in absolute terms and relative to that from disposals to the trenches. Given the very conservative nature of the estimation of releases from the vaults, it is not therefore considered reasonable to limit disposals based on the minimal releases to leachate that in practice will occur from wastes disposed of to the vaults. This also applies to the minimal expected releases to the Drigg Stream. During the PoA, leachate will continue to be monitored and

discharges controlled as necessary in order to demonstrate and ensure that impacts remain acceptable.

For releases to groundwater in the PoA, the assessment calculations are based on the assumption that, due to waste containment and the operation of the leachate management system, no releases occur to groundwater from the vaults [64]. The impacts from groundwater releases are therefore determined by inventories associated with past disposals to the trenches and, importantly, are less restrictive than in the long-term [64,65]. For groundwater, it is therefore appropriate to derive radionuclide limits on the basis of calculations for the long-term as discussed below.

In addition to releases of activity in leachate and gas, doses from external radiation also need to be considered. The outcomes of relevant assessments are reported in reference [64]. Dependent on the location of the external radiation and gaseous release case critical groups, the impacts to these two groups are considered to be partially additive [64] and are discussed further in Subsection 6.3.5. External doses from disposals to the trenches are now negligible as a result of the capping of the trenches. Only disposals to the vaults need therefore be considered. Radiation levels are dominated by the concentration of key gamma emitting radionuclides, in particular Co-60 [64], and requirements for controls based on activity concentrations in future wastes require consideration, in particular for consignments at upper stack positions within the vaults.

6.1.2 Releases to Groundwater

For releases to groundwater, the impacts after the PoA are assessed in terms of the calculated risks to PEGs by a well pathway. This considers the use of groundwater directly for drinking water and also through its use to support growing fruit and vegetables and use by hens and goats. Discharge of groundwater to the marine environment is also considered [65]. The appropriate criterion for deriving radiological capacity values is therefore the risk guidance level of 10^{-6} per year.

Impacts arise as a result of releases from both the trenches and the vaults, and thus the additive impacts need to be considered in the derivation of potential limits. On the same basis, there is no clear rationale for setting limits on an individual vault basis, and so it is appropriate to use this assessment case to derive radiological capacity values on the scale of the vaults as a whole.

6.1.3 Gaseous Release Cases

After the PoA, only C-14 and Rn-222 are of potential importance in terms of potential gaseous releases [66,67].

For C-14, calculations of impacts are made by considering the potential exposure of members of a PEG that lives on the site and uses the site for growing foodstuffs and agricultural purposes. The appropriate criterion in this period is the risk guidance level of 10^{-6} per year. On this basis it is appropriate to average assessed doses in order to derive an appropriate basis for comparison. In principle therefore the impacts of trenches and vaults should be considered additive. However, due to the nature of the PEG and other arguments (in particular, the area cultivated by the PEG is small relative to the footprint of the repository), the assessment assumes that impacts from the vaults and trenches should be considered separately [12,66]. On the same basis, this assessment case is used to derive radiological capacity values on the scale of the vaults as a group; further sub-division of such limits is not considered appropriate.

The potential importance of gaseous releases of Rn-222 from disposed Ra-226 is assessed by considering potential impacts to a member of a PEG that constructs and occupies a house on top of the cap. It is calculated, however, that it will take about 100 days for gases to diffuse through the low-permeability layer of the engineered cap [67]. In this time, any Rn-222 (half-life 3.8 days) migrating through the cap would decay to trivial concentrations with negligible dose potential. Significant doses can only occur in cases in which there is disturbance of the low permeability layer within the cap, such as a building that penetrates through the low permeability layer to reach the gas collection layer. This is a human intrusion case and, moreover, it is found to be less limiting than a case in which a building is constructed on excavated spoil [12], discussed in the next subsection.

6.1.4 Human Intrusion Cases

For human intrusion assessment cases [68], doses are assessed for PEGs associated with an intrusion event, for example to a borehole driller, and for PEGs which are assumed to be exposed to waste previously excavated, for example a smallholder living on land contaminated by a prior intrusion. During coastal erosion of the site, discussed below, additional human intrusion cases are assessed for PEGs that are assumed to make direct contact with exposed wastes. The relevant regulatory criteria for human intrusion cases are the dose guidance levels of 20 mSv per year for short-term exposures and 3 mSv per year for exposures continuing over a period of years respectively.

For all these cases, the potential impacts are determined by the activity concentration in those consignments that are brought to the surface during intrusion or are exposed during coastal erosion. Given the limited areal extent of potential intrusions from the cap surface, and that coastal erosion of the vault and trenches is expected to occur sequentially, intrusions for the trenches and vaults are considered to be independent of each other. The results are therefore used to consider consignment limits for future disposals to the vaults.

6.1.5 Coastal Erosion Cases

The coastal erosion assessment considers impacts to PEGs that make use of the local and regional coast for recreational and occupational reasons and those that consume marine foodstuffs [69]. 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 (in part because it is difficult to reliably estimate the probability of an exposure) and expressed them as an annual dose. It is, therefore, appropriate to use the 20 μ Sv per year dose level advised by the GRA as appropriate to cases that are assumed to occur [18]; this is equivalent to the risk guidance level of 10^{-6} per year for a case with a probability of one.

The reference case for the coastal erosion assessment is based on all vaults being eroded at the same time, and prior to erosion of the trenches [69]. The assessment also considers other potential orientations for coastal recession but concludes that the case of all vaults being eroded simultaneously is cautious. On this basis the vaults and trench impacts are independent and also the distribution of radionuclides between the various vaults is not significant in terms of the resulting exposures. This assessment case is therefore used to derive radiological capacity values on the scale of the vaults as a group.

6.1.6 Low-activity Sources

Low-activity sources present the potential for specific exposure conditions not covered in the above assessments. At present, such sources are disposed of at the LLWR but only if they cannot be managed by alternative means and according to conditions agreed with the Environment Agency in 2005.

During coastal erosion of the site, such source containers or individual sources may be present on the beach and the foreshore and encountered by an individual. Consideration has therefore been given to the doses that would arise if persons were to encounter, examine and, in the case of individual sources, take home such sources [70]. For this situation, the impacts are assessed in comparison with the 20 μSv per year dose criterion [18], equivalent to the risk guidance level of 10^{-6} per year, on the cautious assumption that such exposure will occur. For protection of the skin, the equivalent dose limit given by ICRP of 50 mSv per year for public exposure has been used [71]. These assumptions have been used in the assessment to derive a basis for WAC (Subsection 6.5).

6.1.7 Summary

The use of the various assessment cases for deriving radiological capacity values and potential setting of limits is summarised in Table 6.1. It can be seen that these can be grouped into four main categories:

- Total vault limits: gaseous doses for the PoA and groundwater, gaseous C-14 and coastal erosion cases in the long-term.
- Consignment limits: external doses for the PoA and human intrusion cases in the long-term.
- Limits for low-activity sources: Contact with such items during coastal erosion in the long-term.

These sets of cases are discussed in Subsections 6.3, 6.4 and 6.5 respectively.

Table 6.1 Treatment of assessment cases in the derivation of radiological capacity values and potential limits

	Release Route	Regulatory Criteria	Basis for Potential Limits
PoA	Gaseous releases	0.3 mSv per year dose constraint.	Total vault limits after allowance for the trenches and external radiation.
	Liquid discharges	Vault releases are minimal and not a basis for setting limits.	
	Groundwater releases	Impacts in the long-term are more restrictive and used as a basis for limits.	
	External dose	0.3 mSv per year dose constraint.	Controls on consignments principally at upper stack levels.
Long-term	Groundwater	Risk guidance level of 10^{-6} per year.	Total vault limits after allowance for trench disposals.

	Release Route	Regulatory Criteria	Basis for Potential Limits
	Gaseous releases	Risk guidance level of 10^{-6} per year for C-14.	Total vault limit, independent of trench disposals.
	Human intrusion	Dose guidance levels of 3 and 20 mSv per year dependent on exposure duration.	Consignment limits for vault disposals (both general and for upper stack levels).
	Coastal erosion	20 μ Sv per year dose, equivalent to the risk guidance level of 10^{-6} per year.	Total vault limit, independent of trench disposals.
	Low-activity sources	20 μ Sv per year dose, equivalent to the risk guidance level of 10^{-6} per year.	Limits for low-activity sources.

6.2 Establishment of Radionuclide Screening Criteria

The assessment cases identified above could be used directly to specify individual limits for every radionuclide considered in the assessment. However, it is considered appropriate to undertake a 'screening' step first to identify radionuclides that cannot make a significant contribution to peak impacts. This 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 the findings of the work carried out for the Environment Agency [32], 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.'*

Screening of radionuclides has already been carried out to select radionuclides of potential importance to the ESC and consideration in the assessments [72]. The radiological capacity values 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 for some radionuclides are very large and essentially meaningless in practice. To minimise the complexity of the radiological controls, a screening process has been introduced to ensure individual radiological capacities are only specified for radionuclides that require individually specified control.

An appropriate basis for screening is provided by the upper limit placed on disposals by the 4 and 12 GBq t⁻¹ LLW limits as given in the current Permit for the LLWR [21]. These are also part of UK policy and UK Strategy for the management of LLW [73,74]. The projected LLWR waste inventory is also defined with reference to these limits as only LLW is accepted for disposal to the LLWR.

Screening criteria have been 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 therefore those that have radiological capacities greater (less restrictive) than the value assigned to 'Others'.

- 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, 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 criteria for alpha and beta activities, combined radiological capacity screening values of 300 GBq t⁻¹ and 1,000,000 TBq have been derived for consignment activity and total vaults activity respectively³. These values represent 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⁻¹ 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⁻¹ LLW limits and because their true radiological capacity values 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 subsequent subsections therefore, the screening criteria noted above are applied. The use of this approach for 'other' radionuclides is included in the illustration of the Sum of Fractions approach in Subsection 3.3.

³ The maximum activity of unspecified nuclides cannot exceed the LLW limits of 4 and 12 GBq t⁻¹ for alpha and non-alpha emitting radionuclides respectively, 16 GBq t⁻¹ 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⁻¹ (16 GBq t⁻¹ divided by 300 GBq t⁻¹ equals ~ 0.05). Assuming a maximum quantity of waste in the vaults of about 3 million tonnes, the 300 GBq t⁻¹ consignment based radiological capacity value equates to approximately 1,000,000 TBq (16 GBq t⁻¹ x 0.001 TBq GBq⁻¹ x 3,000,000 t divided by 1,000,000 TBq equals ~ 0.05).

6.3 Controls on Total Inventory

6.3.1 Period of Authorisation

For the PoA, the assessment cases considered as a basis for deriving radiological limits are those based on gaseous releases (Subsection 6.1.1). In this period the appropriate regulatory criterion is the 0.3 mSv per year dose constraint. Doses from H-3, C-14 and Rn-222 (from disposed Ra-226) are assessed to assumed critical groups that spend significant amounts of time and grow some foodstuffs adjacent to the site [64]. These impacts are determined by the total inventory, rather than activity concentrations on a consignment basis, and by the releases from the trenches and vaults in total.

Radiological capacity values derived for the vaults [64] are shown in Table 6.2. These are based upon impact calculations that do not include contributions from the trenches or from exposure due to external irradiation. These aspects are discussed further in Subsection 6.3.5 in setting limits on disposals.

Table 6.2 Radiological capacity values for gaseous release during the Period of Authorisation

Radionuclide	Radiological Capacity (TBq) ⁴
H-3	27,000
C-14	3000
Ra-226 (Rn-222)	14

6.3.2 Groundwater

In the groundwater assessment, radiological capacities have been calculated based on the risk guidance level of 10^{-6} per year [18]. Results have been reported [65] for potential impacts that might arise to PEGs associated with:

- Users of water extracted from a well in the vicinity of the site for drinking, growing crops and raising livestock.
- Fishermen who both catch and consume fish from local coastal waters.
- Users of the Irt estuary who fish for and consume shellfish from the estuary.
- Farmers that make use of water from the Drigg stream.

Radiological capacity values have been calculated corresponding to the peak impacts for the reference case, which assumes erosion of the site commences after 1000 years [65].

Examination of the calculated radiological capacity results shows that, for nearly all radionuclides, the well pathway presents the highest potential impacts and thus the most restrictive radiological capacities for all but a few radionuclides. The only exceptions, for radionuclides remaining after screening, are for the stream pathway. These are Ca-41, Mo-93 and Pb-210, for which the radiological capacities for the stream and well cases are within a factor of two, and Cs-135 and Ag-108m for which

⁴ Here, and in subsequent Tables, radiological capacity values are given to two significant figures in recognition of the underlying accuracy of the underlying assumptions rather than the more precise values cited elsewhere in the ESC.

the assessed risks based on the reference inventory for the stream pathway are low at 4×10^{-12} and 5×10^{-11} per year respectively.

As the well pathway presents the most restrictive radiological capacity set, this has been used as the basis for specifying capacity controls, using the Sum of Fractions approach. This is consistent with the objective of minimising the number of cases used for the capacity calculations in order to avoid over-complexity in the setting of control limits. The resulting calculated capacities are given in Table 6.3. Radionuclides with capacities less restrictive than the screening level are not listed and are included within the 'Others'. For this pathway, this includes H-3, with a radiological relatively high capacity value of 1,100,000 TBq 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.

As discussed in Subsection 6.1.2, for the groundwater cases allowance in the Sum of Fractions calculation needs to be made for the additive impacts from both vaults and trenches. The contribution from the trenches to the peak risk for the well pathway in the reference case is assessed as about $0.002 \times 10^{-6} \text{ y}^{-1}$ [65]. This represents a very small contribution to the Sum of Fractions. Whilst in principle the Sum of Fractions could be adjusted based for this, it is considered this would imply an unrealistic degree of accuracy in the derived radiological capacity numbers, and in the use of the risk guidance level, and that this is not necessary.

Table 6.3 Radiological capacity values for groundwater

Radionuclide	Radiological Capacity Values (TBq)
C-14	370
Cl-36	34
Ca-41	3,200
Mo-93	270
Tc-99	110,000
I-129	1.4
Pb-210	4,200
Ra-226	49,000
Pa-231	900,000
U-233	370,000
U-234	720,000
U-235	640,000
U-236	410,000
U-238	760,000
Np-237	55,000
Others*	1.0E+06

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

6.3.3 Gaseous Releases

For the reasons presented in Subsection 6.1.3, requirements for total inventory controls on the basis of the gaseous release pathway are only required for C-14. No such controls are required for other radionuclides; however consignment limits are presented in Subsection 6.4.2 based on human intrusion including consideration of Rn-222.

As described in reference [12], for the projected total vault inventory of 5.5 TBq, we calculate C-14 labelled gas fluxes from the engineered vaults at 100 years after disposal that would imply doses to a self-sufficient smallholder growing vegetable/fruit and grazing animals on the cap that are above the risk guidance level, assuming that such an exposed group is present. At 300 years after disposal, the calculated fluxes are such that the calculated doses to the exposed group are consistent with the risk guidance level.

The models used to calculate the C-14 labelled gas fluxes, and consequent dose and risk impacts, contain a number of cautious simplifications and assumptions. The primary cautious simplification is that the specific biogeochemical conditions and degradation processes within C-14 bearing waste packages are not considered and, hence no credit is given to the protection of the C-14 bearing wastes from the general vault biogeochemical conditions. Other cautious assumptions are that there will be fully saturated conditions in the vaults, and the start of degradation and biogeochemical evolution in all vaults will occur at the same time. Further, it has been assumed that an exposed group will be present, its habits have been chosen cautiously and the model used to estimate the partitioning of C-14 into plants may also be pessimistic. In view of these cautious assumptions, we believe that through improved modelling we will be able to demonstrate dose and risk impacts from the release of C-14 labelled gas that are consistent with the risk guidance level.

In the event that we cannot reliably demonstrate impacts consistent with the risk guidance level at 100 years after disposal, we note that the only action required to prevent the dose pathway under consideration would be to place restrictions on the use of the cap for agriculture or kitchen gardening. This could be readily achieved through land ownership arrangements and land covenants set up before the end of the PoA. We consider that such arrangements could be reasonably expected to prevent undesirable uses of the cap area for the order of 200 years, at which time, even according to our current models, the calculated impacts would be consistent with the risk guidance level.

Hence, we consider that it is appropriate to set a radiological capacity for the vaults of 6 TBq, sufficient to accommodate the projected future inventory.

We consider that this approach is consistent with the regulatory guidance given the cautious nature of the current assessment models and assumptions. We also note that for waste streams that exceed defined trigger levels (discussed in Subsection 8.1), consignors must provide a demonstration that disposal at the LLWR is the appropriate disposal route and consistent with the principle of use of BAT. The latter will include consideration of material types and any additional controls required within the vaults. If necessary, an emplacement strategy could be considered and implemented (Subsection 8.3).

6.3.4 Coastal Erosion

In the coastal erosion assessment, radiological capacities have been calculated based on an annual dose criterion of 20 μSv per year equivalent to the 10^{-6} GRA risk

criterion [18]. Results have been reported [69] for exposure groups who may be exposed to eroded radioactivity as a result of:

- Recreational use of the coastline adjacent to the LLWR.
- Occupational use of the St Bees to Ravenglass coastline.
- Consumption of local marine foodstuffs.

Analysis of the results for these three cases shows that for all radionuclides impacts to either the recreational or marine foodstuff PEG lead to the most restrictive capacity values [69]. The occupational beach user case is therefore not considered further. Results for the retained groups are given in Table 6.4. Radionuclides with radiological capacities in excess of the screening level of 1,000,000 TBq are not listed and are included as 'Others'. This category includes relatively few radionuclides, examples being Sr-90, Cs-137, Pb-210 and Cm-242.

Of these two exposure groups, for the majority of radionuclides the recreational beach user case gives rise to the more restrictive capacities. The significant exceptions for which the marine foodstuffs case is more restrictive are C-14, Tc-99, I-129 and Ra-226. Given that radionuclides of significance in LLW are identified for each of the two assessment cases, the two sets of radiological capacity values in Table 6.4 are both appropriate for control purposes.

Table 6.4 Radiological capacity values for coastal erosion

Radionuclide	Radiological Capacity Values (TBq)	
	Recreational Beach User	Marine Foodstuffs Case
C-14	530,000	180
Cl-36	16,000	-
Se-79	100,000	400
Zr-93	140,000	70,000
Nb-94	5.3	53,000
Mo-93	64,000	79,000
Tc-99	210,000	9,000
Ag-108m	34	2,500
I-129	1,800	780
Cs-135	130,000	170,000
Ra-226	6.4	3.8
Th-229	26	48
Th-230	8.2	4.6
Th-232	3.0	59
Pa-231	16	130
U-233	160	340
U-234	820	620
U-235	58	2,900
U-236	2,100	7,100
U-238	330	6,900
Np-237	41	1,400
Pu-238	750,000	-
Pu-239	200	420
Pu-240	210	460

Radionuclide	Radiological Capacity Values (TBq)	
	Recreational Beach User	Marine Foodstuffs Case
Pu-241	38,000	130,000
Pu-242	180	420
Am-241	1,300	4,500
Am-242m	13,000	89,000
Am-243	49	540
Cm-243	150,000	350,000
Cm-244	75,000	170,000
Cm-245	65	280
Cm-246	240	600
Cm-248	2.9	130
Others*	1,000,000	1,000,000

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

6.3.5 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, as discussed in Subsection 6.1, are considered in order to establish a suitable overall basis for controls. The relevant radiological capacity values are:

- Gaseous release (both during the PoA and in the long-term), with values as presented in Table 6.2 and with the addition of the 6 TBq limit for C-14.
- Groundwater, with values presented in Table 6.3.
- Coastal erosion, with values presented in Table 6.4.

It is useful to first consider the groundwater and coastal erosion cases. Consideration of the results for these cases (Table 6.3 and Table 6.4) shows that the three different cases are the most limiting for different radionuclides. Controls based on the three sets of radiological capacity values in Table 6.3 and Table 6.4 are therefore appropriate for use in the Sum of Fractions methodology.

For gaseous radionuclides, for the PoA cases, in principle the Sum of Fractions methodology could be used to set limits. However, it is useful to compare the radiological capacities with the corresponding capacities for groundwater (Table 6.3), coastal erosion (Table 6.4) and for C-14 the long-term gaseous release case limit of 6 TBq (Subsection 6.3.3). This is shown in Table 6.5.

Table 6.5 Radiological capacity values for H-3, C-14 and Ra-226

Radionuclide	Radiological Capacity (TBq)			
	PoA	After PoA		
	Gaseous Releases	Gaseous Releases	Groundwater	Coastal Erosion
H-3	27,000	-	1,000,000*	1,000,000*
C-14	3,000	6	370	180
Ra-226 (Rn-222)	14	-	49,000	3.8

* Controlled as part of the other radionuclide group.

From Table 6.5, it can be seen that the long-term radiological assessment calculation results provide more restrictive capacity values for both C-14 and Ra-226 than for the

PoA calculations. The capacity values for C-14 of 6 TBq based on the long-term gas pathway calculations and for Ra-226 of 3.8 TBq based on the coastal erosion pathway, will act to limit the total combined dose from these two radionuclides during the PoA period to less than about 80 μSv per year. To control exposure in this period within the 300 μSv per year dose constraint, additional control is therefore only required for H-3.

In setting a limit for H-3, it is also necessary to take account of doses from gaseous release from the trenches and from external irradiation, to ensure the total peak dose remains below the dose constraint. Peak doses for gaseous releases from the trenches are assessed as 11 μSv per year [64]. For external radiation, a peak dose of 7 μSv per year is estimated for a critical group that may also receive the potential dose from the gaseous pathway [64]. Taking these potential doses into account, a limit of 18,000 TBq is derived for H-3 in order to limit the maximum total impact to 0.3 mSv per year.

For control of doses arising from potential gaseous release of C-14 as a gaseous release in the long-term, a limit of 6 TBq is proposed (as discussed in Subsection 6.3.3). The other assessment cases are less restrictive.

In summary, to provide controls in accordance with regulatory criteria, the required capacity limits are those in Table 6.3 and Table 6.4, to be applied using the Sum of Fractions methodology, plus additional limits of 18,000 TBq for H-3 and 6 TBq for C-14.

We have concluded, as discussed in Subsection 6.1, that there is no requirement to subdivide the controls for the vaults to set limits for individual vaults arising from the assessment calculations. We will, 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 Subsection 8.1.

Consideration has also been given as to whether 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, consideration also needs to be given to the potential requirement for limits on the quantities of radioactivity on a smaller scale. This section presents the derivation of concentration limits for disposed wastes.

The current Permit for the LLWR includes activity concentration limits of 4 GBq t^{-1} for alpha emitting radionuclides and 12 GBq t^{-1} for all other radionuclides [21]. These limits are applied to each consignment disposed of, which can be of up to 40 m^3 in volume [21]. There are no other restrictions within the Permit in terms of activity concentration limits. The limits are the basis of current UK LLW policy [73] and the UK Strategy [74] for the management of LLW. We are not seeking to change these limits.

As discussed in Subsection 6.1, some of the scenarios and assessment cases presented elsewhere in the ESC show that some exposure situations are determined by localised activity concentrations as opposed to the total quantities disposed. Relevant assessment cases are those that involve potential human intrusion into and direct contact with wastes [68]. The cases 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 worker PEGs.
- Members of groups who might spend significant amounts of time on the cap area subsequent to intrusions, represented as site occupier and smallholder PEGs.
- 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 scavenger and organised materials recovery PEGs.

Further descriptions and details of these cases are given in the assessment report [68]. In using the results of the human intrusion 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 too could the laboratory analyst working on retrieved borehole drilling materials. The same also applies for those cases associated with coastal erosion, namely the informal beach scavenger and organised materials recovery persons. In contrast, it is considered within the assessment that trial pits during site investigation work and excavations for construction are typically limited to a depth of about 5 m. Given the thickness of the cap overlying the wastes, this means excavation of any significant quantities of waste material is limited to the upper stack positions. It is also such events that are the more limiting in terms of subsequent doses to other individuals who might live or have a smallholding on the contaminated ground.

In addition, doses from external radiation need to be considered. For the reasons discussed below, these are expected to be dominated by consignments placed at upper stack levels.

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 of low-activity sources 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

As described above, assessment calculations for potential impacts to the borehole driller, lab analyst, informal beach scavenger and organised material recovery PEG cases all consider the potential for exposure to all layers of waste and therefore are considered as a potential basis for setting limits on all consignments. Radiological capacity values have been calculated for each of these cases [68]. For the borehole driller, laboratory analyst and organised materials recovery cases, the radiological capacity values are based on the of 20 mSv per year dose guidance level [18] because it is considered that such exposures would only occur to any single individual for very limited periods of time. For the informal beach scavenger however, such exposures might occur over a number of years and the radiological

capacity values have been derived based on the 3 mSv per year dose guidance level [18].

For the borehole driller and lab analyst, times of intrusion of 100 and 1000 years are considered. These encompass the range of times, after the assumed period of 100 years of institutional control following completion of disposals and before the assumed time of coastal erosion of the site. For the informal beach scavenger and organised material recovery cases, the reference time of 1000 years is considered.

Examination of the calculated radiological capacity results shows that for nearly all radionuclides, assessments of potential impacts to the informal beach scavenger PEG lead to the most limiting capacity values. The exceptions (noting the screening level of 300 GBq t⁻¹, see Subsection 6.2) are Ac-227, Pu-238, Am-242m and Cm-243 for which intrusion at 100 years for the borehole driller PEG is more restrictive. However for each of these radionuclides (with derived radiological capacity values of 85, 16, 7.4 and 110 GBq t⁻¹ respectively) sufficient control is provided by the 4 and 12 GBq t⁻¹ LLW limits and by the controls derived below.

It is appropriate therefore to identify radiological capacity values for control purposes on the basis of assessed impacts to the informal beach scavenger PEG, as the most limiting case. The resulting values are given in Table 6.6. Radionuclides with capacities less restrictive than the screening level are not listed and are included within the 'Other's'. The 'other' radionuclides include H-3, C-14, Co-60, Sr-90 and Cs-137.

Table 6.6 Radiological capacity values for all consignments

Radionuclide	Radiological Capacity Values (GBq t ⁻¹)	Radionuclide	Radiological Capacity Values (GBq t ⁻¹)
Nb-94	0.22	Np-237	1.2
I-129	70	Pu-239	1.4
Ag-108m	1.1	Pu-240	1.6
Ra-226	0.26	Pu-241	240
Th-229	0.54	Pu-242	1.5
Th-230	0.45	Pu-244	0.58
Th-232	0.11	Am-241	8.1
Pa-231	0.28	Am-242m	60
U-233	4.2	Am-243	1.1
U-234	16	Cm-245	0.85
U-235	2.1	Cm-246	1.9
U-236	21	Cm-248	0.099
U-238	9.4	Others*	300

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

We have identified that, in practice, very few waste streams would require control on the basis of the values in Table 6.6. This is because, for many radionuclides, the 4 and 12 GBq t⁻¹ LLW limits provide sufficient control.

For the reference inventory [4] there are only six waste streams that have Sum of Fractions, based on the Table 6.6 data, that exceed a value of 1 [53]. Of these, the two most significant waste streams are (a) radium-contaminated soil from luminising facilities at a variety of defence sites, with a Sum of Fractions value of about 15 dominated by Ra-226 and a disposal volume of about 450 m³ and (b) a Harwell decommissioning waste stream, with a Sum of Fractions value of about 1.6

dominated by Pa-231 and disposal volume of about 1860 m³. The inventory data for both these waste streams are expected to be significantly revised in future UKRWIs and that the Sum of Fractions values based on revised inventory data will be less than one. The four other waste streams have volumes of less than 10 m³. It is therefore concluded that in practice there will only be very few consignments that have the potential to have activity levels exceeding a Sum of Fractions value of one based on the values in Table 6.6. It is likely that in most years no such consignments will occur.

Based on this, and the additional factors identified below, it has been concluded that acceptance of limited numbers of consignments with Sum of Fraction values exceeding one, but limited within the 4 and 12 GBq t⁻¹ limits, would limit exposures in accordance with the regulatory guidance. The following factors are considered important:

- 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 radiological capacity values 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 a member of the scavenger PEG encountering one, or more, such consignments.
- The average assessed dose from the vaults based on the reference inventory, including the higher activity Ra-226 wastes, is less than 0.03 mSv per year (supporting information to reference [68]). This is about two orders of magnitude lower than the dose guidance level. The majority of consignments therefore are of very low significance. It can also be noted that the limits derived in Subsection 6.3 will provide an effective constraint on levels of exposure from informal beach scavenging for the majority of consignments.
- There are significant conservatisms in the assessment used to derive the radiological 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 for controls on wastes given the very low number of potentially significant consignments.
 - The more likely wastes that would exceed the radiological capacity values are those containing Ra-226. These wastes are typically in the form of soil materials that will have a limited residence time in the eroded beach area once subject to the action of coastal processes. This will be a significant factor in limiting such exposures.
 - Such soil type wastes are most unlikely to be of any significant interest to informal beach scavengers and therefore time spent in their immediate vicinity will be less than assumed in the assessment.
 - 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 assessment cases considered here, namely the borehole driller, laboratory analyst and organised materials recovery PEGs. The capacity values calculated for these cases are for most radionuclides less restrictive than for the beach scavenger PEG, typically by a factor of about 5 to 10 for the more restrictive radionuclides. As for the scavenger PEG, for all these cases, 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 PEGs 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.

It is therefore concluded that the 4 and 12 GBq t⁻¹ LLW limits provide a significant degree of control, but that the following additional controls should be introduced. Firstly, there will be review by LLWR of waste streams against the derived radiological capacity values, using the radiological capacity values in Table 6.6 in order to identify those with potential to give rise to consignments with Sum of Fraction values exceeding 1. Such waste streams would only be accepted after consideration of:

- Their place within the UK Strategy for LLW management and the role for alternative waste management options. This will need to include demonstration by the consignor that a Best Available Technology (BAT) assessment has been carried out demonstrating that disposal at the LLWR represents the appropriate waste management option.
- Evaluation of the nature of the waste in terms of its physical composition, size, durability, form of the activity and potential interest to an informal beach scavenger. Wastes that might have significant duration periods or attractiveness if exposed on the beach would not be accepted.

Secondly, because waste stream activity data are an average, it is recognised that review at the waste stream level may not necessarily identify all potential consignments with Sum of Fraction values exceeding one. We will therefore also apply the radiological capacity values in Table 6.6 to identify consignments with Sum of Fraction values exceeding one. All such consignments would then be managed as part of an emplacement strategy to minimise the potential for exposures to more than one such consignment.

The objective of an emplacement strategy in this context is to exclude co-location of such wastes. This would include that no more than one such consignment would be placed in a single stack or adjacent to another stack with such wastes. These review and emplacement requirements will be incorporated in to the existing waste acceptance process operated by LLWR as discussed in Subsection 8.1.

The above system of controls is based on measures to be taken by LLWR. In addition, consideration will be given to the additional controls that are necessary. It is considered that the direct application of this Sum of Fractions approach at a consignment level would require all consignors to carry out a disproportionate level of work in order to implement it across all consignments, given that in practice it would only affect very few consignors and consignments. Consideration has therefore been given to whether a simpler approach, still based on radiological capacity, would provide consignors with a means of identifying consignments that would require to be

managed by LLWR within an emplacement strategy. For this, an approach based on trigger levels has been derived, in which consignors would need to request prior approval from LLWR for wastes that exceed the trigger levels (and consignors would not apply the full Sum of Fractions methodology).

Consideration of the radiological capacity results in Table 6.6 shows that some radionuclides are sufficiently controlled by the 4 and 12 GBq t⁻¹ LLW limits, for example I-129 and Pu-241. For many of the radionuclides, the maximum levels in any waste stream in the reference inventory are less than about 1% of the radiological capacity values in Table 6.6. On this basis, the potentially more significant radionuclides are those shown in Table 6.7.

Subject to further evaluation, the application of consignment trigger values in Table 6.7 as a WAC is considered a pragmatic and proportionate basis to enable consignors to identify consignments with significant amounts of these key radionuclides and which therefore require prior approval. This would augment the assessment at the waste stream and consignment levels by LLWR using the full set of radiological capacity values given in Table 6.6.

Table 6.7 Trigger levels applicable to all consignments

Group	Radionuclide	Trigger Level (GBq t ⁻¹)
Group 1	Total Nb-94 + Pa-231 + Ra-226 + Th-232	0.1
Group 2	Total Ag-108m + Np-237 + Pu-239 + Pu-240 + Am-241	1.0

In summary, it is concluded that the above basis for control is sufficient to ensure, with a high degree of confidence, that regulatory dose guidance levels would not be exceeded and that this is a reasonable basis for setting radiological controls. Control would be maintained by LLWR, both at the waste stream and consignment level, based on the Sum of Fractions methodology and by consignors using the trigger levels as a practical basis for consignment control. The control system and emplacement strategy to manage these higher activity consignments is seen as part of our approach to optimisation of operational practices at the LLWR and of waste management plans in the UK.

6.4.2 Controls on Upper Level Consignments

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

Human intrusion

Of the human intrusion cases [68], those for the trial pit excavator, builder, site occupier and smallholder PEGs are those only exposed to upper layers of waste due to the depth of the excavations associated with these cases. These assessment cases have therefore been considered to assess whether specific additional restrictions need to be put in place.

The cap overlying the wastes has a minimum thickness of 3 m of structured layers plus at least 1 m of profile material immediately overlying the wastes [5]. This means

that excavation of any significant quantities of waste material is limited to the top 1 m of wastes. This is equivalent to the upper stacking level of consignments for those in standard 20 m³ containers. (The assessment conservatively excludes the profiling materials and hence assumed the top two containers [68].)

Radiological capacity values have been calculated for each of the four assessment cases identified above. For the trial pit excavator and builder cases, the radiological capacity values are based on the of 20 mSv per year dose guidance level [18] because it is considered that such exposures would only occur to any single individuals for very limited periods of time. For the site occupier and smallholder, who are assumed to be on the site after excavations have taken place, such exposures might occur over a number of years and the radiological capacity values have been derived based on the 3 mSv per year dose guidance level [18]. Results have been calculated for times of intrusion of 100 and 1000 years. These encompass the range of times, after the assumed period of 100 years of institutional control, before the potential disruption of the site through coastal erosion.

The assessments results indicate that impacts to the trial pit excavator and builder PEGs lead to calculated capacities that, for all radionuclides, are less restrictive than for the other two cases [68]. The trial pit excavator and builder cases are not therefore considered further. The retained radiological capacity values, for the site occupier and smallholder PEGs, are given in Table 6.8. For each radionuclide the most restrictive value is shown in bold. Radionuclides with capacities less restrictive than the screening level are not listed and are included within the 'Others'. A limited number of radionuclides are screened on this basis, an example being Co-60 with a high radiological capacity value due to its relatively short half-life of 5.27 years.

The results also show that each of the two remaining cases is the more restrictive for a significant number of radionuclides, with the smallholder and food pathways dominant for C-14 and Cl-36, external irradiation being the more limiting component for Nb-94 and Ag-108m and inhalation of Rn-222 daughter activity limiting for Ra-226 and Th-230. Both the site occupier and smallholder cases are therefore considered further in setting limits.

Table 6.8 Radiological capacity values for site occupier and smallholder cases

Radionuclide	Radiological Capacity Values (GBq t ⁻¹) at Stated Time			
	Site Occupier		Smallholder	
	100 years	1000 years	100 years	1000 years
H-3	-	-	290	-
C-14	-	-	0.012	0.013
Cl-36	19	19	0.0023	0.0023
Ni-63	-	-	77	-
Sr-90	13	-	0.51	-
Zr-93	260	260	210	210
Nb-94	0.0054	0.0055	0.0086	0.0088
Mo-93	68	79	0.84	0.98
Tc-99	-	-	0.076	0.076
Ag-108m	0.0064	0.028	0.010	0.045
I-129	2.8	2.8	0.32	0.32
Cs-135	270	270	5.4	5.4

Radionuclide	Radiological Capacity Values (GBq t ⁻¹) at Stated Time			
	Site Occupier		Smallholder	
	100 years	1000 years	100 years	1000 years
Cs-137	0.15	-	0.23	-
Pb-210	7.0	-	0.25	-
Ra-226	0.00012	0.00017	0.00011	0.00017
Ac-227	0.57	-	0.97	-
Th-229	0.029	0.032	0.030	0.032
Th-230	0.0027	0.00032	0.0025	0.00031
Th-232	0.0031	0.0031	0.0047	0.0047
Pa-231	0.020	0.020	0.027	0.027
U-233	1.7	0.30	1.0	0.27
U-234	2.5	0.065	1.2	0.060
U-235	0.069	0.065	0.10	0.097
U-236	4.8	4.8	1.7	1.7
U-238	0.38	0.37	0.47	0.46
Np-237	0.046	0.046	0.065	0.065
Pu-238	0.97	190	5.9	210
Pu-239	0.41	0.42	2.4	2.5
Pu-240	0.41	0.45	2.5	2.7
Pu-241	12	51	41	170
Pu-242	0.43	0.43	2.6	2.6
Pu-244	0.024	0.024	0.040	0.040
Am-241	0.42	1.8	1.4	5.8
Am-242m	0.36	15	1.3	52
Am-243	0.054	0.059	0.093	0.10
Cm-242	190	-	-	-
Cm-243	0.86	-	1.5	-
Cm-244	29	160	160	-
Cm-245	0.12	0.10	0.23	0.22
Cm-246	0.49	0.56	2.7	3.1
Cm-248	0.0031	0.0031	0.0050	0.0050
Others*	300	300	300	300

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

Taking the results of both cases, radiological capacity values calculated at 100 years (the end of institutional control) for many radionuclides provide the most restrictive set. Exceptions are evident for a few radionuclides, notably U-234, for which the ingrowth of daughter radionuclides leads to significantly more restrictive values at later times. It is therefore considered that conservatively controls should be based on the most restrictive results assuming intrusion at any time during the period from 100 years after disposals are completed up to 1000 years after present.

In contrast to the assessment cases discussed in Subsection 6.4.1, the 4 and 12 GBq t⁻¹ LLW limits provided sufficient control on their own only for relatively few radionuclides. Therefore a Sum of Fractions approach is necessary for those consignments located within 5 m of the cap surface.

In applying this approach, it is possible to consider using two sets of values, based on the most restrictive value for each of the site occupier and smallholder cases, or to use a single set using the most restrictive value for each radionuclide for either PEG. Whilst the latter is conservative, it is unlikely to lead to significantly greater numbers of consignments requiring emplacement management, estimated to be about 10% of consignments in most years with a short-term peak of approaching 50% for a few years around 2020 [53]. It is therefore considered that, subject to further evaluation, the most appropriate set of controls for upper stack position consignments is to apply the most restrictive radiological capacity value for each radionuclide based upon those presented in Table 6.8. These are given in Table 6.9.

Table 6.9 Radiological capacity values for upper stack position consignments

Radionuclide	Radiological Capacity Values (GBq t ⁻¹)	Radionuclide	Radiological Capacity Values (GBq t ⁻¹)
H-3	290	U-234	0.060
C-14	0.012	U-235	0.065
Cl-36	0.0023	U-236	1.7
Ni-63	77	U-238	0.37
Sr-90	0.51	Np-237	0.046
Zr-93	210	Pu-238	0.97
Nb-94	0.0054	Pu-239	0.41
Mo-93	0.84	Pu-240	0.41
Tc-99	0.076	Pu-241	12
Ag-108m	0.0064	Pu-242	0.43
I-129	0.32	Pu-244	0.024
Cs-135	5.4	Am-241	0.42
Cs-137	0.15	Am-242m	0.36
Pb-210	0.25	Am-243	0.054
Ra-226	0.00011	Cm-242	190
Ac-227	0.57	Cm-243	0.86
Th-229	0.029	Cm-244	29
Th-230	0.00031	Cm-245	0.10
Th-232	0.0031	Cm-246	0.49
Pa-231	0.020	Cm-248	0.0031
U-233	0.27	Others*	300

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

As expected, the values for upper level consignments in Table 6.9 are significantly more restrictive than the values in Table 6.6. It is noted that an emplacement strategy study on waste streams carried out for LLWR identified that it would be beneficial to exclude wastes with high Ra-226 content from the upper levels of the vaults [75]. Emplacement of high Ra-226 content wastes at vault levels not likely to be intruded in to by such excavations is also a conclusion of the human intrusion assessment [68].

Consideration has also been given to the number of consignments that are assumed to be included in the assessments that lead to potential exposures to the site occupier and smallholder. For these two assessment cases the volumes of waste material that could be disturbed as a result of the intrusions considered are assumed

to be 800 and 100 m³ respectively. It is, however, considered impractical to operate an emplacement strategy that takes into consideration averaging over a small number of consignments. It is therefore considered that the radiological capacity values given in Table 6.9 should be applied to each consignment within 5 m of the cap surface. Again, this approach is conservative.

The control system for upper level consignments will therefore comprise:

- Identification by LLWR, from consignors' waste stream information, of those waste streams that have the potential to comprise consignments with Sum of Fraction values exceeding 1. The volume of such wastes, both on an annual basis and in total, will be kept under review to ensure it is compatible with the ability to ensure placement below the upper stack levels.
- Calculation by LLWR of the Sum of Fraction values for each consignment before its arrival at the LLWR to identify those with Sum of Fractions values exceeding a value of 1. All such consignments to then be excluded from upper stack positions as part of an emplacement strategy. It is expected that the number of these consignments is such that individual consignors need not specifically identify them but that this can be done, prior to consignment arrival, by LLWR.
- In addition, as part of the approach to optimisation of operational practices, all such identified consignments as far as practicable to be placed at the lower stack positions. This is in order to minimise the potential for boreholes, for example, to intersect such consignments and subsequently the potential for small quantities of such wastes to be left as material in the surface environment.

External radiation (PoA)

For external radiation, doses are assessed to three critical groups. These are for local residents occupying the east and west of the site, coal yard workers to the north of the site and dog walkers adjacent to the site [64]. Of these, the most limiting in terms of external radiation is an assumed hypothetical critical group to the west of the site for which a peak dose of about 0.15 mSv per year is estimated. Such a group does not currently exist and is unlikely to exist during the PoA, as the land is a Site of Special Scientific Interest [64] and as such protected from development. Assessed doses to the other critical groups are a factor of at least two lower. These doses are dominated by the contribution of Co-60 to the radiation levels around the site perimeter [64].

Calculations have been carried out to derive the levels of radionuclides that would give rise to the 0.3 mSv per year dose constraint [64]. The results show that for all radionuclides except Co-60, the derived limits are less restrictive than the 4 and 12 GBq t⁻¹ LLW limits. The values for all other radionuclides are such that the LLW limits will provide sufficient control to limit the doses from external radiation to within the 0.3 mSv per year dose constraint (including consideration of doses from gaseous releases).

For Co-60, the derived value is about 0.6 GBq m⁻³, equivalent to about 0.2 GBq t⁻¹, and significantly more restrictive than the 12 GBq t⁻¹ limit. Whilst in principle limits on the level of Co-60 in future disposals could be set on this basis, a number of considerations have been identified:

- The basis of the derived limits is conservative, as discussed above, in that they consider a hypothetical critical group that is assumed to reside to the west of the site.

- It is the cumulative inventory in the uncapped vault(s) that determines the impacts, and not individual consignments. Averaging over a significant number of consignments is therefore appropriate.
- In practice it is the Co-60 content of consignments exposed at any given time that is the dominant determinant of radiation levels. This includes consignments in upper stack positions plus those on open stack sides, although the former are likely to be dominant. Radiation from consignments within stacks is effectively shielded by absorption of radiation within the waste matrix by those consignments above and surrounding them. Of particular importance therefore are those consignments in the upper level of each stack and those consignments that, for operational reasons, might be exposed for significant periods of time. (This is supported by the observation that dose rates adjacent to the site have been relatively constant over the last ten years or have shown decreases [76], despite the increasing inventory and stack heights within Vault 8).
- Dose rates in the vicinity of the site can be limited by operational controls. An emplacement strategy for higher dose rate consignments would therefore contribute to dose rate limitation. In addition, if required, additional controls could be introduced such as partial capping of exposed wastes.
- Doses to on-site workers will also need to be brought into any consideration of controls to limit radiation levels.
- Placing inventory controls to limit radiation levels on waste packages might be unnecessarily restrictive on UK waste management and decommissioning plans if alternative means of control, as indicated above, can be established.

It is therefore concluded that control of doses from external radiation is best achieved by a combination of monitoring of future radiation levels adjacent to the site, by regular assessment of potential doses and if necessary by waste emplacement measures.

If required, an emplacement strategy would be based on excluding high dose rate consignments from the upper stack positions and from other positions in which the consignment might not be shielded by other consignments for significant lengths of time for operational reasons. If such emplacement measures are necessary, we will consider further the basis for identifying such consignments based on historic data on radiation levels, the derived capacity for Co-60 discussed above [64] and operational practices.

On this basis, it is concluded that that no specific controls should be placed on the inventory of radionuclides in order to control radiation levels on waste packages and associated doses.

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 waste streams and consignments that require additional assessment because of their potential importance in terms of exposure of persons who might contact the wastes during coastal erosion of the site. These wastes will be identified by LLWR using the radiological capacity for each radionuclide in Table 6.6 in the Sum of Fractions methodology. If, after further assessment on the basis discussed in Subsection 6.4.1, very limited numbers of consignments of such wastes are accepted for disposal, then they will be managed as part of an emplacement strategy (Subsection 8.3). In addition,

consideration will be given to the role of setting trigger levels in the WAC based on the values in Table 6.7.

- 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. These consignments will be identified by LLWR using the values for radiological capacity for each radionuclide in Table 6.9 in the Sum of Fractions methodology. All such consignments will then be managed as part of an emplacement strategy (Subsection 8.3). In addition, dependent on the results of dose rate monitoring around the site, consideration will be given to the need for an emplacement strategy for high dose rate consignments.
- For the majority of consignments, no additional controls are considered necessary and sufficient control is provided by the 4 and 12 GBq t⁻¹ LLW limits.

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.

6.5 Controls on Low-activity Sources

To identify potential requirements for controls for low-activity sources, appropriate assessment results have been considered. These relate to assessment cases concerning potential situations arising after the onset of facility disruption through coastal erosion whereby source containers have been distributed, with other waste, on the beach and may be broken open by wave action on the cobble storm beach [70]. Interaction with such sources is assumed to occur as early as 300 years after disposal, as this represents the earliest time at which any such event could occur based upon projected ranges of timescales for commencement of site disruption by coastal erosion. Exposure calculations consider impacts to a beach user, for example a walker or beachcomber, who either interacts with a single source container or finds and takes away one or a small number of individual sources. The PEG is assumed to exist and moreover, no account is taken for the probability that such an interaction could occur within the defined timescales. The impacts are assessed in terms of:

- The dose due to handling and/or proximity to a source container on the beach/foreshore.
- The dose due to prolonged proximity to an individual source taken away from the beach/foreshore.
- The dose to a localised area of skin due to handling, or pocketing of an individual source.

Doses are assessed in comparison with a 20 µSv per year dose criterion, equivalent to the risk guidance level of 10⁻⁶ per year. In addition, for protection of the skin, the equivalent dose limit given by ICRP of 50 mSv per year for public exposure has been used [77].

Based on the assessment results [70], a system for waste acceptance has been derived which takes account of the half-lives and the nature of the radiation of different radionuclides. This sets limits on both individual sources and also limits to control the number and activity of sources in any single container of mixed sources

and the associated packaging requirements. Where more than one source is disposed, a Sum of Fractions approach is proposed to limit the total quantities. These controls are summarised in Table 6.10 and Table 6.10.

Table 6.10 Limits for control of individual low-activity sources

Radionuclide Group	Characteristics	Examples	Limit (MBq)
Group A	Long-lived radionuclides that emit, or decay to short-lived progeny that emit, significant photon emissions.	Ra-226, Th-232, Np-237	1
Group B1	Long-lived radionuclides that do not emit, or decay to short-lived progeny that emit, significant photon emissions.	C-14, Cl-36, Pu-239, Am-241	10
Group B2	Radionuclides with half-life less than about 100 years that emit, or decay to short-lived progeny that emit, significant photon emissions or bremsstrahlung.	Sr-90, Cs-137	10
Group C1	Radionuclides with half-life less than about 100 years that do not emit, or decay to short-lived progeny that emit, significant photon emissions or bremsstrahlung.	Ni-63	100
Group C2	Any radionuclides with half-life less than about 10 years.	Co-60	100

Table 6.11 Conditions for consigning of low-activity sources

Condition	Rationale
1. The activity of any individual source shall not be greater than 1 MBq for Group A, 10 MBq for Group B and 100 MBq for Group C radionuclides.	Required to limit the impact of individual sources.
2. As much extraneous packaging as practical must be removed. In addition sources that might be potentially attractive should, as far as reasonably practicable, be disfigured.	Required to make sources unattractive and eliminate buoyancy.
3. The sources shall be mixed with sufficient grout, in a clean paint-tin-type container, in order to provide reasonable containment of each source. The container should be 'topped up' with grout so as to minimise any air space or void within the container and the tin closed tight.	Provides limited shielding (for beta emissions) and primary containment of the sources. Topping up prevents buoyancy and crushing of the container.
4. The total activity of a source container must be limited such that: $[I_A + I_B/10 + I_C/100] / V \leq 5 \text{ MBq l}^{-1}$ where I_A , I_B and I_C are the total activities (MBq) of radionuclides of Groups A, B and C respectively and V is the volume of the container (l).	Required to limit the impact of source containers.

Our proposals will allow source containers with specific activity above the definition of LLW, especially if containing larger sources with half-life less than 10 years, but only subject to the requirement that the overall consignment must be consistent with the 4 and 12 GBq t⁻¹ LLW limits.

On the basis of the assessment [70], we have identified that there is no longer a requirement for the current WAC restriction of one source container per consignment (Table 8.2, paragraph L2.6).

In all instances, a specific waste stream characterisation will continue to be required detailing the normally required waste stream information and, in addition, the source registration references (if available), number of discrete sources in container, radionuclide(s) and activity of each source, and total activity of each radionuclide at the time of consignment for disposal.

We consider that the proposed conditions provide flexibility to dispose of somewhat higher activity sources than under the existing WAC, and hence avoid the accumulation of such sources in storage facilities, while still providing a high level of long-term radiological protection.

We have also considered the need for additional controls to limit the activity associated with other particular items of wastes. As for low-activity sources, this could be of potential importance following coastal erosion of the site during which people might be exposed to items on the beach and foreshore.

It is considered that the preferred approach is to develop further guidance on this in consultation with the Environment Agency and with waste consignors. This would develop further the work carried out as part of the ESC on low-activity sources [70]. It would seek to distinguish between those sources of waste in which there is direct control of the level of activity, for example filter systems, from those in which the activity is essentially present as inadvertent contamination. Separate consideration might also be given to cases in which the activity is present as loose contamination or associated with less durable materials, and hence can be expected to be less environmentally persistent, compared with cases such as activated radionuclides in durable materials. Consideration can also be given to high-value items that might be preferentially identified and handled, if exposed during coastal erosion.

6.6 Fissile Controls

Small quantities of fissile materials are present within the LLW disposed of at the LLWR. The quantities are, however, small enough to qualify as 'fissile excepted' under IAEA Transport Regulations for the shipment of these materials through the public domain [78]. Nevertheless, WAC 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.

An updated criticality assessment has been carried out as part of the ESC [79]. The methodology adopted for the assessment incorporates elements of 'relevant good practice' from the British Standard on criticality safety [80] and also from guides and standards published by the IAEA. Also, where appropriate, the assessment follows the criticality safety principles developed by the NDA Radioactive Waste Management Directorate, which is responsible for ensuring the safe long-term disposal of higher activity radioactive wastes in the UK. 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.

The assessment has shown that:

- The fissile material as emplaced is dispersed throughout the wastes such that waste materials provide sufficient dilution of the fissile material to ensure that criticality is physically impossible.
- The post-closure design features of the LLWR passively minimise the water infiltration 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 criticality.

The assessment concluded with recommended revised WAC for control of fissile radionuclides. The fissile inventory of a LLW consignment must be:

- For uranium radionuclides:
 - (a) less than 150 g (U-233 + U-235 + Pu-239), with the specific restriction on U-233 only applicable where the waste is derived from a plant or process which handled separated U-233; or
 - (b) less than 300 g U-235 if the average uranium enrichment does not exceed 5% U-235 with respect to total uranium; or
 - (c) less than 1000 g U-235 if the average uranium enrichment does not exceed 1.6% U-235 with respect to total uranium; or
 - (d) unrestricted if the average uranium enrichment does not exceed 0.93% U-235 with respect to total uranium, equivalent to that of natural uranium.
- Categories (b), (c) and (d) above may also contain up to 15g of (U233 + Pu239).
- Fissile nuclides other than uranium and plutonium may also be present up to an activity limit of 0.1 GBq t⁻¹.

These limits are applicable to any container filled with waste. For non-containerised wastes, the above limits will be applied pro-rata per 20 m³ of waste.

7 Controls to Limit Non-Radiological Inventory

The regulatory guidance relating to near-surface radioactive waste disposal facilities [18] requires, within Requirement R10, protection against non-radiological hazards to be addressed. As discussed in Subsection 3.1, whilst nationally standards for disposing of hazardous waste need not necessarily be applied, *'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'*. (GRA paragraph 6.4.2)

As part of the 2011 ESC, the non-radiological impacts of the LLWR have been assessed. These are reported in detail in reference [81] and summarised in reference [13]. Results are given in terms of the calculated peak concentrations in the environment from the inventory of disposed contaminants in the trenches and vaults. These are then compared with environmental quality standards to judge their significance.

The non-radiological contaminants assessed have been based on Defra guidance relating to pollution of groundwater and its expectations on how European directives should be implemented [82] and a detailed review of the presence of hazardous substances within trench leachate and at other LLWR monitoring locations [83]. The inventory information for both the trenches and vaults was then developed to establish inventory data for as many of these contaminants as possible. This has resulted in data for contaminants present as bulk materials and for those more specific waste contaminants as declared in the UKRWI [56].

The calculated environmental concentrations have been compared with the quality standards that are considered appropriate for groundwater, based largely on drinking water and environmental quality standards. The approach adopted the most restrictive standard [81]. Results were calculated for impacts associated with the following:

- Groundwater (as a receptor in its own right) located directly beneath the trenches and vaults.
- Exposure arising from groundwater abstraction from a well between the site and the coast.
- Exposure following coastal erosion of the site and the resulting non-radiological contamination of the foreshore and beach.
- Exposure following potential human intrusion into the site following the end of institutional control.
- Exposures to gaseous releases of non-radiological contaminants.

These therefore broadly encompass the same exposure routes as those considered in Section 6 for radiological contaminants and the associated controls, with the addition of impacts to groundwater as a specific receptor, as required to comply with regulatory requirements. The results discussed below, as with the radiological controls discussed in Section 6, are based on the reference case results [81].

In terms of the principal non-metallic constituents of wastes and their degradation products, the assessment includes:

- Benzene, taken as a degradation product of condensation polymers, non-halogenated rubber, thermoplastics and some organics and oils.
- Vinyl chloride, taken as representative of a range of organohalogen compounds and as a degradation product of halogenated rubbers and plastics.
- Phenol, taken as a degradation product of mineral oils and hydrocarbons.

The impacts of these are all assessed as very low, principally because of their limited persistence and hence the low calculated concentrations in the environment. On this basis it is concluded that the non-metallic constituents of wastes do not require limitation in terms of the disposed inventory. An exception to this is oils which must be suitably fixed in a solid matrix in order to ensure that no visible oil or grease will be released by leaching as required by the discharge Consent for the Marine Pipeline [62].

The other major components of waste materials are the principal metallic constituents of wastes. Of these, several have been shown by the assessment to be of very low significance, including Al, Sn and U. Other metallic constituents (including Cr, Cu, Fe, Pb, Mo and Ni) are however of potential importance with calculated environmental concentrations a significant fraction of or in excess of the limits after the end of the PoA. However, the exceedances relate to substances present in steels, common alloys and copper, rather than to hazardous substances. We consider that the performance provided by the LLWR would be similar to that provided by any landfill after the end of the period of management and note that assessments are not required or conventionally undertaken for a landfill after this period. In terms of broad consistency with policy for the management of landfill wastes, we suggest that the proposed disposals of these materials to the LLWR are acceptable. It is considered that explicit control of metallic wastes is not appropriate for what are essentially routine metallic wastes.

Pending further discussion with the Environment Agency on these issues, we propose that an exception should be Pb. Lead is principally present in bulk metallic form, often used as a radiation shielding material and is a potential pollutant. The Pb in bulk form in LLW can be readily identified and managed. We intend to continue, as is current practice (paragraph L1.16.1) [20], to have controls on disposals of Pb to the LLWR, based on surface area and solubility considerations.

Consideration has been given in the non-radiological assessment to potential impacts of waste degradation gases. Whilst degradation gases are flammable and, in the case of hydrogen sulphide toxic, it is considered that these are sufficiently controlled by the gas management programme and that no controls in terms of inventory are required.

Specific consideration has been given to asbestos, as a known constituent of LLW. Asbestos is carcinogenic when fibres are airborne and inhaled. Asbestos is therefore of potential significance in the coastal erosion case. We have therefore concluded that asbestos should be excluded from disposals unless conditioned or treated to produce a form that would be acceptable if released on to the foreshore during coastal erosion. This is likely to involve the material being fixed, prior to consignment, in a solid matrix within a container, such methods to be agreed with LLWR prior to use.

The above discussion has considered the need for controls on the principal components of wastes. Further consideration has however been given to the potential significance of the more minor constituents of waste streams that may arise that could have impacts of potential significance. This could arise because either the contaminants might be present in potential waste stream in forms with significantly

different leaching characteristics to those used in the non-radiological assessment or for contaminants not yet assessed in the reference inventory.

Whilst the majority of waste streams do not contain non-radiological contaminants that could give rise to potentially significant impacts, those that contain potentially significant non-radiological contaminants are identified by means of the current WAC requirements [20] relating to the Hazardous Waste Regulations and, under the Environmental Permitting regime, the Groundwater Regulations (Table 8.2, paragraphs L1.16 and L1.17 respectively). These require that if consignors wish to consign such wastes then the wastes must be made safe and appropriate documentary evidence, including the results of leach testing, must be provided. Approval is required from LLWR prior to consigning such wastes.

The non-radiological assessment included results in the form of non-radiological capacity values (similar to those discussed in Section 6 for radiological contaminants) that in principle might be applied to assess the significance of such wastes. However we have concluded that the results of the non-radiological assessment are too conservative to apply directly without further consideration. The results of the environmental monitoring programme for the LLWR do not show any significant elevated levels of contaminants that are associated with disposals [13]. Furthermore, for wastes in the vaults there is a high degree of containment and a leachate collection and management system. Monitoring of leachate quality will continue throughout the period of disposal operations and the period of institutional control. On this basis we consider that the measures in place at the LLWR provide a level of protection against the non-radiological hazards of the wastes that is no less stringent than those for disposals at other sites of non-radioactive hazardous wastes and therefore consistent with the GRA guidance (paragraph 6.4.2).

We propose to review the current WAC relating to the identification of potentially significant non-radiological contaminants to ensure that they reflect good practice and provide the required information. Potentially significant contaminants are considered those that are:

- Categorized as hazardous under the Hazardous Waste Regulations.
- Considered either a hazardous substance or as a non-hazardous pollutant, if present in the waste in soluble⁵ form, under the Environmental Permitting regime.

For wastes containing such non-radiological contaminants, review and assessment of the data provided by consignors will be carried out to determine if substances can be disposed safely at the LLWR. We recognise that it would be helpful to develop further the basis for assessing the acceptability of wastes that contain potentially significant quantities of non-radiological substances. As part of taking this work forward, we would find it helpful to discuss this further with the Environment Agency in terms of the relevant criteria and associated timescales that should be applied to such controls.

In conclusion, it is considered that the principal constituents of LLW do not require control in terms of their non-radiological impact with the exception of specific measures for Pb, asbestos and oils, as identified above. In addition, the current WAC will be reviewed to ensure that they provide a means to identify, and require provision of the sufficient information, to assess the safe acceptance of specific waste streams that contain potentially significant levels of non-radiological contaminants.

⁵ Soluble is a defined term in the WAC.

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8 Implementation

The objective of this section is to describe our plans for the implementation of the findings of this work in terms of the necessary controls on waste acceptance. Implementation will be through three principal means:

- The overall waste acceptance process managed by LLWR.
- Revisions to the WAC issued to waste consignors.
- An emplacement strategy within the disposal vaults to manage specific waste streams and waste consignments.

We intend to bring the necessary changes into operation in a planned and phased manner, with priority given to those aspects that if not enacted would have potentially significant environmental safety implications. 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:

- The need to ensure an integrated approach throughout the waste acceptance process.
- The need to ensure compliance with both the findings of the ESC in terms of waste acceptance and the Permit for the site [21].
- The need to develop specific revisions to the WAC and for these to be brought into operation by consignors.

As noted in Subsection 3.1, the Permit for the site places a number of requirements on LLWR in terms of the types and quantities of waste that can be accepted for disposal. These include annual 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. We intend to apply for a revised Permit and at that stage will seek amendments to the Permit to reflect the findings of the ESC. In the interim period, we will ensure compliance with the requirements of both the ESC and Permit.

In terms of WAC, these are updated from time to time for a number of reasons, for example developments in acceptance arrangements and in waste management practices. As part of the process of introducing revised WAC, discussions are held with waste consignors to ensure the necessary requirements are clearly represented and to enable the efficient introduction of the required changes. As is current practice, all revisions to the WAC are issued to the Environment Agency prior to their introduction.

The requirements of the ESC in terms of waste acceptance, identified in Sections 4 to 7, are summarised in Table 8.1. As identified above, implementation will be by changes to the waste acceptance process itself, the WAC and by a waste emplacement strategy. Table 8.1 also shows the principal means by which they will be introduced. It can be seen that some of the required changes are implemented by modifications to the WAC, whilst others will require changes to the waste acceptance process. Several of the new required amendments result in the need for emplacement measures. In all instances, overall control and verification will be provided by the integrated approach currently in place for waste acceptance.

These aspects are discussed further in the following subsections.

Table 8.1 Summary of requirements identified from the ESC

ESC Requirement	Means of Implementation		
	Waste Acceptance Process	WAC	Emplacement Strategy
Waste containment (Subsection 4.1)	✓	✓	
Grouted waste form (Subsection 4.2)	✓		
Retention of absorbed liquids (Subsection 4.3)		✓	✓
Treatment of powders (Subsections 4.1, 4.3 and 5.7)		✓	
Control of inaccessible voidage and biodegradable materials (Subsection 4.4)	✓	✓	✓
Control on the metal content of wastes (Subsection 4.4)	✓		✓
Restrictions on complexing agents (Subsection 5.6)		✓	
Controls on total vault activity (Subsection 6.3.5)	✓		
Controls on consignment activity (Subsection 6.4.3)	✓	✓	✓
Controls on low-activity sources (Subsection 6.5)		✓	
Fissile controls (Subsection 6.6)		✓	
Controls on non-radiological content of waste (Section 7)		✓	

It is worth noting that, in many cases, the WAC act as absolute requirements that must be met to ensure the underlying operational or safety objectives are met. This includes those WAC that are derived directly from the Permit for the site issued by the Environment Agency [21]. It is recognised however that given the wide range and diversity of wastes, it is not practical to produce WAC that comprehensively encompass the full range of wastes that can be accepted. The approach taken is to establish WAC that define the requirements for the majority of wastes consigned. Wastes that do not meet the WAC may still be acceptable after assessment on a case-by-case basis. A waste consignor, using an appropriate form supported by relevant information, can apply for variations. LLWR then documents the basis for acceptance or rejection. In some cases these can lead to additional constraints including the need for specific controls on emplacement. Examples of these are particularly heavy consignments, non-containerised wastes or consignments that require additional grouting after emplacement in the vault. These also are managed as part of emplacement operations but are not addressed further here.

8.1 Waste Acceptance Arrangements

8.1.1 Current Acceptance Process

LLWR issues both an overview set of WAC that introduces and applies to all its waste management services [19] and service specific WAC. The latter includes the WAC that apply for disposal of wastes to the LLWR (see Table 8.2) [20] and those for

waste treatment [84,85]. For wastes to be accepted, they must satisfy the criteria detailed in both the overview set of WAC and the service specific WAC. The overview WAC and those for disposals to LLWR are summarised here to give an understanding of the current WAC applicable at the site.

The waste acceptance overview document provides a summary of the waste acceptance procedure [19]. It gives consignors key information about LLWR, its waste treatment and disposal services, and acts as an introduction to the process and requirements for consigning waste to LLWR. This includes the consigning of LLW for disposal at the LLWR and also the other waste management services that we offer to consignors.

To consign waste to LLWR for treatment and/or disposal, there are a number of prerequisites that must be in place. These are a disposal Permit (previously termed authorisation) issued under the Environmental Permitting (England & Wales) Regulations 2010 (or the equivalent regulations for Scotland and Northern Ireland) and an agreement in principle plus a waste services contract from LLWR. In appropriate cases transfrontier shipment authorisations and third party waste agreements must also be in place.

The overall waste acceptance process also includes the necessary details for delivery of wastes and communication routes between customers and LLWR, details of record keeping requirements and a glossary of defined terms used within the process. The waste acceptance process is managed within LLWR as part of its overall quality 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.

The overview WAC principally relate to the need to address waste management strategy and optimisation issues. A central aspect of this is the requirement for implementation of the waste hierarchy approach [73] to ensure that only wastes that need to be consigned to the LLWR are sent for disposal and that the volume of such wastes is minimised.

We have reviewed the overview WAC [19] as part of this work on the ESC. We have concluded that it forms an essential part of our approach to optimisation of the use of the LLWR but that no significant additions or changes are required at the current time to ensure consistency with the ESC or for any other reasons.

The waste acceptance procedure includes the following elements: waste forecasting, waste characterisation, waste assurance, waste enquiry, waste consignment and waste receipt. Process diagrams, guides, forms and templates to facilitate understanding and aid implementation of the process, accompany these. Further details are provided on the LLWR website. Each of these steps of the waste acceptance process is summarised below. The basis for the changes necessary to implement the ESC requirements are identified in Subsection 8.1.2.

Waste forecasting is the stage of the acceptance process that requires customers to provide a 12 month forecast (updated every six months) of their waste treatment and disposal requirements in terms of volume, radioactivity content and container supply requirements. LLWR must ensure that the total of all activity allocation requests does not exceed the annual radiological limits specified in the Permit for the LLWR. Following review of the forecast, we issue an allocation of capacity to the customer in terms of volume and activity and also ensure that sufficient containers are available to meet customer requirements.

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 site's Permit. Such wastes are only accepted after full assessment that disposal at the LLWR is the optimum waste management option for that waste stream and that its disposal is consistent with the UK Strategy for LLW management [74].

Waste assurance requires customers to provide re-assurance to LLWR 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 waste acceptance procedure and the WAC. 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 assurance monitoring of waste consignments. It is noted that the Environment Agency also carries out its own independent checking of LLW consigned to the LLWR.

Waste enquiry is the starting point for consigning a specific volume of waste to LLWR. It is designed to promote early engagement between customers and LLWR in order 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 consignment is the stage at which consignors gather data as waste is packaged into a consignment. The Waste Consignment Information Form is then completed to provide detailed information on the contents of a specific container of waste. The completed form is sent to us at least five days prior to the intended date of arrival of the waste at the LLWR. This stage includes a range of checks we carry out 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.

Waste receipt is the last element to be followed in consigning waste. This stage 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 LLWR 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.

8.1.2 Basis for Controls

Controls against total vault limits

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 6.3.5. Currently, disposals are controlled consistent with the set of annual activity limits stipulated in the Permit for the site. Comparison of these limits with those derived in this document shows that the Permit is more restrictive for the specified radionuclides, except for I-129 for which the revised limit based on the groundwater pathway is marginally more limiting. For radionuclides not specified in the Permit, those for which the revised limits are more limiting and potentially significant are Cl-36 for the groundwater pathway and Nb-94, Ag-108m and Th-230 for coastal erosion. We will apply for a revised Permit that will include proposals to update and replace the annual limits. Up until the time at which any Permit is issued, the annual limits will be maintained. In addition, a system will be developed to provide a means of control based on the limits derived in this report for total vault disposals.

The revised waste inventory control system will need to provide a basis for the summation of radionuclide data for disposals to all the vaults. This will enable control to be achieved and demonstrated against the total vault limits. Currently, as described above, planned disposals are based on 12 month forecasts and control against annual limits. Actual disposal data are recorded using a waste tracking system. These two systems are therefore currently independent of each other. The basis of the revised control system based on ESC requirements will need to be an integrated system incorporating all previous data for vault disposals up to any given time against which forecast and actual disposals can be assessed and controlled. A key aspect of this system will be the means to carry out the Sum of Fractions assessments to provide a means of control against the set of limits given in Table 6.3 and Table 6.4 for groundwater and coastal erosion respectively. Additionally, systems will be incorporated to control against the limits of 18,000 TBq for H-3 and 6 TBq for C-14 based on gaseous releases.

The existing waste tracking system that records the details of waste consignments is currently being updated to provide a more flexible and comprehensive data recording system. We will review this work and develop the necessary basis for total inventory control. This will incorporate the data for existing disposals to Vault 8.

Planning and control of the total inventory is currently carried out as part of the waste forecasting stage and waste stream characterisation stages. 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. With the introduction of controls on total vault activity levels, there is a need for waste forecasting to consider longer time periods than the currently yearly basis described above. We are considering whether this could be best achieved by a combination of:

- Radionuclide data in the UKRWI [56] as a long-term forecasting tool against which total capacity can be planned.
- The waste forecasting stage of the waste acceptance process for shorter-term forecasting. The current system would need modification to request the data necessary for the required radionuclides. This will also be used if necessary to assist in operational planning in support of the emplacement strategies.

We will develop this further and discuss potential developments with the Environment Agency and with consignors in order to ensure all necessary requirements are addressed and that the wider implications are considered.

In terms of waste stream acceptance, we review waste stream information at the waste characterisation stage of the current waste acceptance process. This includes, as described above, activity 'trigger levels' to identify waste streams that would take up a disproportionate fraction of the total activity radiological capacity compared with their volume. Whilst this aspect will be continued in order to ensure the requirements of the current Permit are met, further development will be necessary to implement the requirements of the ESC.

A revised basis for the trigger levels will be developed. As described above, such wastes are only accepted after full assessment that disposal at the LLWR is the optimum waste management option for that waste stream and that its disposal is consistent with the UK Strategy for LLW management [74]. Whilst the details of a revised trigger system are still to be considered in detail, a suitable basis is expected to be based on the relative volume of the waste stream to that of the total vault capacity and on the Sum of Fractions value for that waste stream. As part of this work, specific measures will be developed in relation to the assessment and control of waste streams with significant levels of C-14 (Subsection 6.3.3) and the potential requirement for specific emplacement measures (Subsection 8.3).

Controls against consignment limits

Controls against consignment limits require two stages within the acceptance process.

Within the waste characterisation stage, the review of waste streams will be used to identify those waste streams that will require management as part of emplacement strategies. In terms of the consignment activity limits, the Sum of Fractions controls identified in Subsection 6.4.3 will be applied.

Firstly, those waste streams that exceed the Sum of Fractions using the radiological capacity values in Table 6.6 will be identified as part of the overall approval process against the criteria given in Subsection 6.4.1. A control basis will be developed to ensure that the total volume of all such waste streams is consistent with the basis for the ESC as given in Subsection 6.4.1.

Secondly, those waste streams that exceed the Sum of Fractions in Table 6.9 will be identified to ensure that the objectives of the emplacement strategy for excluding such wastes from the upper level of the vaults can be successfully implemented.

The waste consignment stage of the waste acceptance process will also need to be augmented by additional review by LLWR, as part of the prior notification of consignment details. At this stage the individual consignments need to be identified that require to be managed as part of an emplacement strategy, based on the Sum of Fraction values in Table 6.6 and Table 6.9 and based on radiation dose rate if this is identified as necessary.

Also, as is current practice, any consignments will be identified that require any emplacement restrictions or additional measures to be taken. These would include, for example, those that exceed the consignment limit for inaccessible voidage plus biodegradable waste, or have a high metal content, and that therefore require emplacement to control total stack composition. A list of all such consignments will then be provided to the site operations team, prior to consignment delivery, with the measures to be taken for each clearly identified.

One of the requirements of the ESC is that wastes that include absorbed liquids must have applied loads not exceeding 400 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).

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.

Reporting and review arrangements

As part of the management systems within LLWR, routine reporting against the current radiological controls is carried out. We plan to integrate a regular review, and additional controls as appropriate, into the current reporting systems to ensure compliance with requirements of the ESC in terms of waste acceptance. The key aspects that will be kept under review are expected to be:

- Actual and forecast usage of the radiological capacity of the site in terms of the vault limits in Subsection 6.3.5.
- Identification of waste streams that exceed the waste stream trigger levels for either total activity, discussed above, or consignment activity controls given by the radiological capacities in Table 6.6 and Table 6.9.
- Actual and forecast numbers of consignments that require to be managed as part of emplacement strategies.

As part of this work on waste acceptance, it has been identified that there are requirements in terms of assumptions within the ESC that need to be kept under review. These are:

- That waste containment will ensure that activity releases are such that impacts during the PoA are minimised (Subsection 4.1).
- That the overall levels of grout present in the vaults do not change significantly from that assumed in the ESC (Subsection 4.2).

Neither of these requirements places specific restrictions on waste streams or consignments. Whilst any potentially significant developments in regard to either of these would be identified as part of control procedures, we plan that an annual review of these aspects becomes part of our reporting arrangements. Formal recognition of these requirements, by annual review, will provide a means of demonstrating control against potentially significant trends in waste form and waste packaging.

In addition, at a more detailed level there will be changes necessary to the documentation associated with the controls on wastes and to the associated support systems. 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

The intention of this section is to demonstrate 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 4 to 7. As discussed

in Subsection 8.1, we will now take forward the detailed finalisation of revised WAC as part of the programme of ESC implementation.

The current WAC for disposals of LLW to the LLWR [20] are presented in three parts:

- 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.
- Radiological properties. This includes radioactivity limits, fissile controls and radiation and contamination criteria.
- 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 ESC are given in Table 8.2. It includes our conclusion as to whether the requirement is retained or where necessary amended. In each case the objective of the WAC is briefly summarised and, for ESC-related aspects, a cross-reference is given to the relevant section of this report.

Table 8.2 Current WAC and basis for expected revisions⁶

Paragraph	Current WAC	Our Conclusions
1	<p>Introduction</p> <p>This document defines the <i>Waste Acceptance Criteria</i> for the disposal of low-level radioactive waste by <i>LLWR</i> at the <i>Low Level Waste Repository</i>. This disposal service is available for waste that is not suitable for treatment or not selected for treatment and for secondary waste produced as a result of a treatment service.</p>	To be retained with no changes required. No implications from the ESC.
1.1	<p>Scope</p> <p>This Waste Acceptance Criteria (WAC) document represents the full requirements for the Packaging, Receipt, Grouting and Disposal of <i>Low Level Waste</i> at the Low Level Waste Repository. The criteria apply to each consignment of waste to LLWR.</p>	No implications from the ESC. To be retained with no changes required.
1.2	<p>Service Supplier</p> <p>The Low Level Waste Disposal Service is provided by LLWR at the Low Level Waste Repository in West Cumbria.</p>	No implications from the ESC. To be retained with no changes required.
1.3	<p>Process</p> <p>Customers deliver low-level waste consignments to the Low Level Waste Repository for disposal. Following receipt, the waste is grouted and disposed of by LLWR.</p>	No implications from the ESC. To be retained with no changes required.
1.4	<p>Waste Acceptance</p> <p>For a <i>Waste Consignment</i> to be accepted by LLWR, it must satisfy the criteria detailed in this document and the Waste Acceptance Criteria Overview document (Reference: WSC-WAC-OVR). Waste will only be accepted from Customers in accordance with LLWR's Waste Acceptance Procedure. In addition, waste is accepted for disposal at the Low Level Waste Repository based on the availability of sufficient volumetric and radiological capacity.</p>	No implications from the ESC. To be retained with no changes required.
1.5	<p>Variations</p> <p>Variations to or waiver of the criteria defined in this document may be allowed but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR. In all cases, approval is required prior to waste being prepared for consignment.</p>	No implications from the ESC. To be retained with no changes required.

⁶ Terms in italics are defined in the associated glossary [3].

Paragraph	Current WAC	Our Conclusions
1.6	<p>Approval in Advance</p> <p>Certain criteria defined in this document state that it is necessary to obtain an Approval in Advance from LLWR. This can be achieved by approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR.</p>	<p>No implications from the ESC.</p> <p>To be retained with no changes required.</p>
1.7	<p>Non-Compliant Waste</p> <p>Any non-compliant wastes consigned to LLWR may require collection by the Customer in accordance with the relevant conditions in the Waste Services Contract.</p>	<p>No implications from the ESC.</p> <p>To be retained with no changes required.</p>
1.8	<p>Defined Terms</p> <p>Defined terms within this document are highlighted in <i>italics</i> and their meanings are presented in the Glossary.</p>	<p>Additional definitions will be provided as part of an updated Glossary. These will include biodegradable wastes and powders.</p> <p>No implications from the ESC.</p> <p>To be retained with no changes required.</p>
2	<p>Waste Acceptance Criteria</p> <p>This section details the Waste Acceptance Criteria for LLWR's Low Level Waste Disposal Service. It is presented in three sections:</p> <ul style="list-style-type: none"> • L1 – Physical and Chemical Properties • L2 – Radiological Properties • L3 – Packaging and Transport Requirements 	<p>No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L1	Physical and Chemical Properties	
L1.1	<p>Waste Treatment and Segregation</p> <p>Waste should not be consigned for disposal if reasonably practicable measures could be adopted to segregate its constituent parts such that alternative waste treatment and / or disposal services could be used to reduce the final volume requiring disposal at the Low Level Waste Repository or to avoid disposal at the Low Level Waste Repository.</p> <p>Waste consigned for disposal shall be either secondary waste resulting from a volume reduction or decontamination treatment process or be regarded as waste that is not suitable for treatment and / or waste that is not selected for treatment. Where waste is not selected for treatment, acceptance will require <i>Suitable Supporting Justification</i> to</p>	<p>The purpose is to conserve volumetric capacity at the LLWR by segregation and / or volume reduction of wastes if reasonably practicable.</p> <p>This is consistent with the assumptions in the ESC on waste strategy and treatment.</p> <p>To be retained with no changes required.</p>

Paragraph	Current WAC	Our Conclusions
	be provided.	
L1.2	<p>Acceptable Waste Only solid radioactively contaminated or activated waste will be accepted for disposal at the Low Level Waste Repository. Waste consigned for disposal must be compliant with the Low Level Waste Repository's Environmental Permit issued under the Environmental Permitting (England and Wales) Regulations 2010 by the Environment Agency (Reference: EPR/YP3293SA). Compliance with the <i>Disposal Authorisation</i> can be achieved by complying with the requirements of this Waste Acceptance Criteria and consigning waste in accordance with the Waste Acceptance Procedure.</p>	<p>The purpose is to conserve volumetric capacity at the LLWR by ensuring only LLW is acceptable. No implications from the ESC. To be retained with no changes required.</p>
L1.3	<p>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.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (a)). The requirement for insolubility in water so far as is reasonably practicable is fully consistent with the assumptions in the ESC in terms of release of radionuclides to groundwater and ensures no significant releases on contact by water (Subsection 4.1). Such control is also potentially required in terms of compliance with the conditions of the Marine Pipeline discharge Consent [62].</p> <p>The low flammability requirement is principally based on operational safety considerations but also is protective of containment (Subsection 4.1). To be retained with no changes required.</p>

Paragraph	Current WAC	Our Conclusions
L1.4	<p>Non-Waste Materials</p> <p>Where materials must be added to the waste, the Customer shall use reasonable means to limit the quantity of non-waste materials present in a <i>Waste Consignment</i>. It is not acceptable to purposely dilute waste or add shielding materials for the sole purpose of achieving compliance with the requirements of this Waste Acceptance Criteria.</p>	<p>The purpose is twofold. Firstly to conserve volumetric capacity at the LLWR by minimisation of addition of non-waste materials for example during waste conditioning such as encapsulation. Secondly to ensure that wastes that would otherwise be unacceptable are not made compliant by dilution with non-waste materials.</p> <p>No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L1.5	<p>Reactive Metals and Materials</p> <p>Waste shall not contain <i>Reactive Metals</i> and other materials which readily react either with water or air with the evolution of heat or flammable gases.</p> <p>Customers shall use reasonable means to limit the accessible surface area of aluminium, zinc and magnesium within the waste and in any case, the total accessible surface area of these metals within a <i>Waste Consignment</i> must not exceed 10m².</p> <p>Painting or wrapping aluminium, zinc and magnesium wastes are acceptable methods to limit the accessible surface area.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (b) (i)).</p> <p>This requirement is principally based on operational safety considerations, together with grout quality considerations. During grouting of wastes reactive metals result in the generation of hydrogen that is both a potential safety hazard and can increase the porosity of the grout, hence adding to voidage. The specification is consistent with no significant additional voidage being generated and ESC assumptions on voidage (Subsection 4.4).</p> <p>The specific requirements in terms of limits for the more commonly present reactive metals aluminium, zinc and magnesium are based on laboratory work supported by evidence from trial grouting of containers with known quantities of such metals.</p> <p>To be retained with no changes required.</p>

Paragraph	Current WAC	Our Conclusions
L1.6	<p>Explosive Materials</p> <p>Waste shall not contain explosive materials.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (b) (ii)).</p> <p>This requirement is principally based on operational safety considerations, but also is protective of containment (Subsection 4.1).</p> <p>To be retained with no changes required.</p>
L1.7	<p>Liquids</p> <p>Waste shall not contain any <i>Free Liquid</i> or liquids with flashpoint less than 21 °C absorbed on solid materials.</p> <p>Any 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) and <i>Suitable Supporting Justification</i> by LLWR. In addition, the following conditions must be met:</p> <ul style="list-style-type: none"> • Any liquid shall, prior to consignment, be fixed in a <i>Suitable Solid Matrix</i> which will not result in release of liquid under applied loads of up to 400 kN/m² • The non-aqueous content of any liquid in the waste shall be conditioned, prior to consignment, so that no visible oil or grease will be released by leaching of the disposed waste form as demonstrated by the <i>Leaching Test</i> 	<p>It is a requirement of the current Permit that only solid waste can be disposed of at the LLWR (Schedule 6, Clause 2 (a)).</p> <p>The exclusion of free liquids is to ensure no significant releases on initial breach of containment (Subsection 4.1).</p> <p>The need to exclude low flashpoint liquids is a Permit requirement (Schedule 6, Clause 2 (b) (iii)). It is principally an operational safety consideration but also is protective of containment (Subsection 4.1).</p> <p>The applied load criterion for absorbed liquids is consistent with the assumptions in the ESC regarding stack heights and emplacement restrictions for current vaults (Subsection 4.3).</p> <p>The requirement for retention of non-aqueous liquids is to ensure compliance with the Marine Pipeline discharge Consent that there be no visible oil or grease [62].</p> <p>To be retained with no changes required.</p>
New		<p>Powders</p> <p>A new requirement will be introduced to limit powders. This will require wastes that primarily</p>

Paragraph	Current WAC	Our Conclusions
		consistent of powders to be conditioned using a method approved in advance by LLWR. This is to limit release in the event of breach of containment during the operational phase (Subsection 4.1), ensure voidage requirements are complied with (Subsection 4.4) and limit the potential for enhance contaminant transport in groundwater by colloidal/particulate materials (Subsection 5.7).
L1.8	<p>Soluble Solids Any discreet <i>Bulk Chemical Compound</i> solid wastes (>1kg mass) which are described as soluble or slightly soluble in cold water (inorganic compounds) and water (organic compounds) in the solubility column of the latest edition of the CRC Handbook of Chemistry and Physics may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR. In addition, the following conditions must be met:</p> <ul style="list-style-type: none"> Any soluble or slightly soluble bulk solid waste shall be fixed, prior to consignment, in a <i>Suitable Solid Matrix</i> which will not readily release that component as demonstrated by the <i>Leaching Test</i> 	<p>It is a requirement of the current Permit that only solid waste can be disposed of at the LLWR that, so far as is reasonably practicable, is insoluble in water (Schedule 6, Clause 2 (a)). See L1.2 also.</p> <p>The requirement to fix soluble solids in a <i>suitable solid matrix</i> is to ensure no significant release on initial breach of containment (Subsection 4.1). Such releases could also potentially be detrimental in terms of compliance with the conditions for non-radiological components of the Marine Pipeline discharge Consent [62] and could potentially give rise to additional voidage (Subsection 4.4)</p> <p>To be retained with no changes required.</p>
L1.9	<p>Strong Oxidising Agents Waste shall not contain strong oxidising agents.</p>	<p>The need to exclude strong oxidising agents is a requirement of the current Permit (Schedule 6, Clause 2 (b) (iv)).</p> <p>This requirement is considered to be based on operational safety considerations and is protective of containment (Subsection 4.1). It is considered that this should be strengthened by an additional requirement to exclude any materials that could lead to significant corrosion of containers within the</p>

Paragraph	Current WAC	Our Conclusions
		lifetime otherwise expected for such containers (Subsection 4.1).
L1.10	<p>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), unless treated, prepared or made safe by a method approved in advance by LLWR.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (b) (v)). This requirement is considered to be based principally on operational safety considerations, but is also protective of containment (Subsection 4.1). To be retained with no changes required.</p>
L1.11	<p>Toxic Materials Waste shall not contain materials which generate or are capable of generating toxic gases, vapours or fumes harmful to persons handling the waste.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (b) (vi)). This requirement is considered to be based principally on operational safety considerations, with no significant implications from the ESC. To be retained with no changes required.</p>
L1.12	<p>Chemical Complexing or Chelating Agents Waste shall not contain chemical complexing or chelating agents.</p>	<p>This is a requirement of the current Permit (Schedule 6, Clause 2 (b) (vii)). To be retained with no changes pending discussions with the Environment Agency to consider a revised definition of complexants (Subsection 5.6).</p>
L1.13	<p>Ion Exchange Materials Waste shall not contain <i>Ion Exchange Material</i> unless conditioned using a method approved in advance by LLWR. This is likely to involve the <i>Ion Exchange Material</i> being fixed, prior to consignment, in a <i>Suitable Solid Matrix</i> which meets the leachable component requirements as demonstrated by the <i>Leaching Test</i>.</p>	<p>Retained to ensure no significant releases on initial breach of containment (Subsection 4.3).</p>
L1.14	<p>Biological, Infectious and Pathogenic Materials Waste shall not contain biological, pathogenic or infectious materials, as listed within</p>	<p>Retained for operational safety considerations, with</p>

Paragraph	Current WAC	Our Conclusions
	Hazard Groups 2, 3 or 4 in the Approved List of biological agents produced by The Advisory Committee on Dangerous Pathogens, unless treated so that no viable micro-organism(s) from Hazard Groups 2, 3 or 4 exist by a method approved in advance by LLWR.	no significant implications from the ESC.
L1.15	<p>Putrescible Waste</p> <p>Customers shall use reasonable means to limit the quantity of <i>Putrescible Materials</i> in the waste and in any case, the total weight within a <i>Waste Consignment</i> must not exceed 1% of the total weight of waste.</p>	<p>In terms of voidage considerations, this will be combined with requirement for biodegradable materials and inaccessible voidage (paragraph L3.4) in order to meet cap performance requirements (Subsection 4.4). The revised requirement is expected to be based on the need to use reasonable means to limit the quantity of biodegradable materials in the waste and, in any case, to limit it so that total potential voidage from all sources does not exceed the derived stack criteria (Subsection 4.4).</p> <p>No additional controls on putrescible materials is required on ESC considerations (Subsection 5.2) but further consideration is being given to the potential operational safety aspects in terms of human health and gas generation. The 1% putrescible limit will be retained pending further consideration of operational aspects. Putrescible materials will be included in the definition of biodegradable wastes.</p>
L1.16	<p>Hazardous Waste</p> <p>The Hazardous Waste (England and Wales) Regulations 2005 (or as amended) apply to a limited amount of radioactive waste as most radioactive waste is subject to the provisions of the Radioactive Substances Act 1993 and is therefore outside the scope of the Hazardous Waste Regulations. However, to fulfil regulatory expectations in relation to disposals at the Low Level Waste Repository, waste containing hazardous waste must be controlled. It may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR. The Form must</p>	<p>This will be reviewed to ensure that it continues to provide the necessary information to enable LLWR to assess such wastes. This will take into account further development of the basis for assessing waste acceptability and discussions with the Environment Agency in terms of the relevant</p>

Paragraph	Current WAC	Our Conclusions
	<p>include details of the components that make the waste hazardous and the levels at which they are present.</p> <p>Materials that are likely to, or actually, possess one or more <i>Hazard Properties</i> shall be assessed and where present be excluded from the waste or made safe prior to any conditioning or mixing with other materials. Customers should use process knowledge to demonstrate that materials do not contain the components listed in Table 1 before resorting to material testing. For the material to be made safe, the hazards or risks shall be removed or reduced, by a method approved in advance by LLWR, to such a level that a <i>Waste Consignment</i> no longer possesses that hazard or risk.</p> <p>It is recognised that not all types of Hazardous Waste are relevant to disposals at the Low Level Waste Repository. Customers are therefore encouraged to consult with LLWR prior to the preparation of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV).</p> <p>A Waste Consignment Variation Form (Reference: WSC-FOR-WCV) is not required for waste containing the hazardous components listed in Table 1 where the concentrations are below the stated Inert Waste leaching limit values.</p>	<p>criteria (Section 7).</p>

Paragraph	Current WAC				Our Conclusions
L1.16 cont.	Table 1: Leaching Limit Values for Inert Waste and Stable Non-Reactive Waste				
	Component	Symbol	Leaching Limit Value (mg/ kg dry substance)		
			Inert Waste	Stable Non-Reactive Waste	
	Arsenic	As	0.5	2	
	Barium	Ba	20	100	
	Cadmium	Cd	0.04	1	
	Total Chromium	Cr total	0.5	10	
	Copper	Cu	2	50	
	Mercury	Hg	0.01	0.2	
	Molybdenum	Mo	0.5	10	
	Nickel	Ni	0.4	10	
	Lead	Pb	0.5	10	
	Antimony	Sb	0.06	0.7	
	Selenium	Se	0.1	0.5	
	Zinc	Zn	4	50	
	Chloride	Cl	800	15,000	
	Fluoride	F -	10	500	
	Sulphate	SO ₄ ²⁻	1,000	20,000	
	Dissolved Organic Carbon	DOC	500	800	
	<p>The Leaching Limit Value should be determined using the standard defined in: BS EN 12457-3: 2002, Characterisation of waste, Leaching Compliance test for leaching of granular waste materials and sludges, Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction).</p>				
	<p>If any Inert Waste leaching limit values in Table 1 are exceeded, a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) is required for waste containing the hazardous components provided the concentrations are below the stated Stable Non-Reactive leaching limit value listed in Table 1.</p>				
	<p>If both sets of leaching limit values in Table 1 are exceeded, a sample of the waste must be fixed in a <i>Suitable Solid Matrix</i> and the new leaching limit value of the monolithic waste form should be determined using the standard defined in EA NEN</p>				

Paragraph	Current WAC	Our Conclusions																																																			
L1.16 cont.	<p>7375:2004, Leaching Characteristics of Moulded or Monolithic Building and Waste Materials, Determination of Leaching of Inorganic Components with the Diffusion Test, 'The Tank Test', Version 1.0, April 2005 published by the Environment Agency.</p> <p>Following this test, if all concentrations are below the Hazardous Waste leaching limit values listed in Table 2, waste may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR. In addition, the hazardous waste shall be fixed, prior to consignment, in a <i>Suitable Solid Matrix</i>.</p> <p>Table 2: Leaching Limit Values for Hazardous Waste</p> <table border="1"> <thead> <tr> <th>Component</th> <th>Symbol</th> <th>Leaching Limit Value (mg/ kg dry substance)</th> </tr> </thead> <tbody> <tr><td>Arsenic</td><td>As</td><td>0.5</td></tr> <tr><td>Barium</td><td>Ba</td><td>20</td></tr> <tr><td>Cadmium</td><td>Cd</td><td>0.04</td></tr> <tr><td>Total Chromium</td><td>Cr total</td><td>0.5</td></tr> <tr><td>Copper</td><td>Cu</td><td>2</td></tr> <tr><td>Mercury</td><td>Hg</td><td>0.01</td></tr> <tr><td>Molybdenum</td><td>Mo</td><td>0.5</td></tr> <tr><td>Nickel</td><td>Ni</td><td>0.4</td></tr> <tr><td>Lead</td><td>Pb</td><td>0.5</td></tr> <tr><td>Antimony</td><td>Sb</td><td>0.06</td></tr> <tr><td>Selenium</td><td>Se</td><td>0.1</td></tr> <tr><td>Zinc</td><td>Zn</td><td>4</td></tr> <tr><td>Chloride</td><td>Cl⁻</td><td>800</td></tr> <tr><td>Fluoride</td><td>F⁻</td><td>10</td></tr> <tr><td>Sulphate</td><td>SO₄²⁻</td><td>1,000</td></tr> <tr><td>Dissolved Organic Carbon</td><td>DOC</td><td>500</td></tr> </tbody> </table> <p>If the concentrations exceed the leaching limit values in Table 2, the hazardous waste is unlikely to be acceptable for disposal at the Low Level Waste Repository. Further</p>	Component	Symbol	Leaching Limit Value (mg/ kg dry substance)	Arsenic	As	0.5	Barium	Ba	20	Cadmium	Cd	0.04	Total Chromium	Cr total	0.5	Copper	Cu	2	Mercury	Hg	0.01	Molybdenum	Mo	0.5	Nickel	Ni	0.4	Lead	Pb	0.5	Antimony	Sb	0.06	Selenium	Se	0.1	Zinc	Zn	4	Chloride	Cl ⁻	800	Fluoride	F ⁻	10	Sulphate	SO ₄ ²⁻	1,000	Dissolved Organic Carbon	DOC	500	
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Nickel	Ni	0.4																																																			
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Paragraph	Current WAC	Our Conclusions
	<p>advice should be sought from LLWR.</p> <p>Conditioning processes may be used to ensure hazardous waste is below the Leaching Limit Value must but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR.</p> <p>The quantity of all hazardous waste in a <i>Waste Consignment</i> must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).</p>	
<p>L1.16.1</p>	<p>Lead</p> <p>Waste containing lead may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR. The form submission must include the following information:</p> <ul style="list-style-type: none"> • Surface area of lead, in m², including both readily accessible surface areas and inaccessible areas, such as Lead encased in steel or cement. • Total volume of lead, in m³ <p>The quantity of all lead in a <i>Waste Consignment</i> must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).</p>	<p>To be retained as a potentially significant non-radiological pollutant known to be used in the nuclear and other industries for radiation shielding. (Section 7).</p>
<p>L1.16.2</p>	<p>Asbestos</p> <p>Waste containing asbestos may be consigned for disposal in accordance with the following requirements:</p> <ul style="list-style-type: none"> • Where the asbestos to be disposed of is <i>Supercompactable Waste</i> that has not undergone high force compaction, the volume of asbestos in a <i>Waste Consignment</i> shall be considered as <i>Inaccessible Voidage</i> and is therefore restricted to the limits specified in L3.4 • Where the asbestos to be disposed of is not <i>Supercompactable Waste</i> or is <i>Secondary Waste</i> that has undergone high force compaction, the volume of asbestos in a <i>Waste Consignment</i> is not restricted • All asbestos consigned for disposal must be double-bagged or double-wrapped in a suitable plastic material and securely tied or sealed. Air should be excluded from the bag or wrapping as far as possible before sealing. In addition, all asbestos wastes must be restrained within the <i>Waste Consignment</i> to prevent floatation of the waste during the grouting process at the Low Level Waste Repository. 	<p>This is consistent with the assumptions in the ESC on voidage (Subsection 4.4). However, to provide additional protection a new requirement will be introduced that asbestos that is not supercompacted must be cemented in an approved container (Section 7).</p>

Paragraph	Current WAC	Our Conclusions
	The quantity of all asbestos in a <i>Waste Consignment</i> must be recorded in the relevant section of the Waste Consignment Information Form (Reference: WSC-FOR-WCI).	
LI.17	<p>Hazardous Substances and Non-Hazardous Pollutants</p> <p>The Groundwater (England and Wales) Regulations 2009 (or as amended) apply to disposals at the Low Level Waste Repository. The disposals of <i>Hazardous Substances</i> and <i>Non-Hazardous Pollutants</i> must therefore be controlled. Waste containing <i>Hazardous Substances</i> and <i>Non-Hazardous Pollutants</i> may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR.</p>	This will be reviewed to ensure that it continues to provide the necessary information to enable LLWR to assess such wastes, with emphasis placed on hazardous substances and non-hazardous pollutants present in the waste in <i>soluble</i> form. This will take into account further development of the basis for assessing waste acceptability and discussions with the Environment Agency in terms of the relevant criteria (Section 7).
L2	Radiological Properties	
L2.1	<p>Radioactive Contaminant</p> <p>The waste within a <i>Waste Consignment</i> 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 <i>Radioactive Contaminant</i> should not exceed 10% of the weight of the <i>Waste Consignment</i>. This limit may be exceeded but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR.</p>	<p>The purpose is to conserve volumetric capacity at the LLWR by ensuring only LLW is acceptable. The 10% is a trigger level, with no explicit basis, intended to identify wastes that are relatively concentrated (compared with the majority of wastes in which the activity is present as a contaminant) and hence take up a disproportionate fraction of the radiological capacity compared with their volume. Such wastes will only be accepted based on an explicit justification being provided and reviewed by LLWR against competing demands on radiological capacity.</p> <p>To be retained with no changes required.</p>
L2.2	<p>Radioactivity Limits</p> <p>The <i>Activity</i> of any <i>Waste Consignment</i> 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"> • 4GBq/t for all alpha-emitting radionuclides 	The 4 and 12 GBq t ⁻¹ LLW limits are part of the current Permit (Schedule 6, Clause 1 (a)) and are used as basis for the inventory used within the

Paragraph	Current WAC	Our Conclusions
	<ul style="list-style-type: none"> 12GBq/t for all other radionuclides <p>In accounting for <i>Activity</i> against these limits, the activity of <i>Decay Products</i> with half-lives of less than three months shall not be accounted for unless they are not in equilibrium or if they form a major proportion of the total <i>Activity</i>.</p>	<p>ESC.</p> <p>Consideration will be given to introducing the additional consignment trigger levels given in Table 6.7.</p>
L2.3	<p>Fissile Radionuclides</p> <p>Waste containing <i>Fissile Radionuclides</i> may be consigned for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR.</p> <p>A Waste Consignment Variation Form (Reference: WSC-FOR-WCV) is not required for waste that meets the relevant requirements stated in L2.3.1 to L2.3.5.</p> <p>There are no exceptions for waste containing Cm-247. A Waste Consignment Variation Form (Reference: WSC-FOR-WCV) is required for all <i>Waste Consignments</i> containing Cm-247.</p>	<p>Required in order to identify consignments requiring fissile controls.</p> <p>To be retained with no changes required.</p>
L2.3.1	<p>Uranium</p> <p>Waste containing U-235 may be consigned provided that the Waste Consignment meets the following requirements:</p> <ul style="list-style-type: none"> All the uranium present is either natural or depleted uranium, or The U-235 content of any Waste Consignment does not exceed 60g 	<p>To be revised in line with the updated criticality case (Subsection 6.6).</p>
L2.3.2	<p>Plutonium</p> <p>Waste containing plutonium may be consigned provided that the <i>Waste Consignment</i> meets the following requirements:</p> <ul style="list-style-type: none"> Total Pu alpha (i.e. Pu-238 + Pu-239 + Pu-240 + Pu-242) does not exceed 0.1GBq/t Pu-241 complies with the Radioactivity Limits defined in L2.2. <p>Waste containing plutonium above these limits may be permitted, subject to safety assessment, but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR.</p>	<p>To be revised in line with the updated criticality case (Subsection 6.6).</p>
L2.3.3	<p>Neptunium</p> <p>Waste containing Np-237 may be consigned provided that the <i>Waste Consignment</i> does not contain more than 4GBq/t of Np-237.</p>	<p>To be revised in line with the updated criticality case (Subsection 6.6).</p>

Paragraph	Current WAC	Our Conclusions																																		
L2.3.4	<p>Americium Waste containing Am-241, Am-242m and / or Am-243 may be consigned provided that the <i>Waste Consignment</i> does not contain more than 0.1GBq/t of each of these radionuclides.</p>	To be revised in line with the updated criticality case (Subsection 6.6).																																		
L2.3.5	<p>Other Fissile Radionuclides Waste containing the <i>Fissile Radionuclides</i> listed in Table 3 may be consigned provided that the <i>Waste Consignment</i> does not contain more than the stated fissile limit, in MBq/t.</p> <p>Table 3: Fissile Radionuclide Limits</p> <table border="1" data-bbox="365 547 768 1153"> <thead> <tr> <th>Radionuclide</th> <th>Fissile Limit (MBq/t)</th> </tr> </thead> <tbody> <tr><td>Th-228</td><td>100</td></tr> <tr><td>U-232*</td><td>1</td></tr> <tr><td>U-233*</td><td>1</td></tr> <tr><td>U-234*</td><td>0.01</td></tr> <tr><td>U-236*</td><td>0.0001</td></tr> <tr><td>Pa-231</td><td>0.1</td></tr> <tr><td>Pa-232</td><td>100</td></tr> <tr><td>Cm-243</td><td>100</td></tr> <tr><td>Cm-244</td><td>100</td></tr> <tr><td>Cm-245</td><td>1</td></tr> <tr><td>Cm-246</td><td>1</td></tr> <tr><td>Cf-249</td><td>1</td></tr> <tr><td>Cf-250</td><td>10</td></tr> <tr><td>Cf-251</td><td>1</td></tr> <tr><td>Cf-252</td><td>1</td></tr> <tr><td>Es-254</td><td>10</td></tr> </tbody> </table> <p>Notes: * Control of these <i>Fissile Radionuclides</i> is only required where artificial means have been employed to enrich the uranium specifically in these radionuclides. Products of U-235 enrichment processes are covered by L2.3.1.</p>	Radionuclide	Fissile Limit (MBq/t)	Th-228	100	U-232*	1	U-233*	1	U-234*	0.01	U-236*	0.0001	Pa-231	0.1	Pa-232	100	Cm-243	100	Cm-244	100	Cm-245	1	Cm-246	1	Cf-249	1	Cf-250	10	Cf-251	1	Cf-252	1	Es-254	10	To be revised in line with the updated criticality case (Subsection 6.6).
Radionuclide	Fissile Limit (MBq/t)																																			
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Cm-245	1																																			
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Cf-250	10																																			
Cf-251	1																																			
Cf-252	1																																			
Es-254	10																																			

Paragraph	Current WAC	Our Conclusions
L2.4	<p>Radiation</p> <p>The maximum radiation level at any point on the external surface of the <i>Disposal Container</i> shall not exceed 2mSv/h.</p>	<p>Required for compliance with Transport Regulations and provides control on doses to on-site workers. External radiation exposures to PEGs will be controlled by other means (Subsection 6.4.2).</p> <p>To be retained with no changes required.</p>
L2.5	<p>Contamination</p> <p>External non-fixed contamination levels on the <i>Disposal Container</i> at the time of consignment shall be as low as reasonably practicable and in any case not more than 0.4Bq/cm² for all alpha-emitting radionuclides and 4Bq/cm² for all other radionuclides averaged over an area of 300cm².</p>	<p>Required for compliance with Transport Regulations and provides control on exposure of on-site workers. It is also protective of potential short-term releases (Subsection 4.1).</p> <p>To be retained with no changes required.</p>
L2.6	<p>Sealed Sources</p> <p>Closed sources, including sealed sources, laminated sources and/or homogeneous sources, as defined in The Radioactive Substances (Waste Closed Sources) Exemption Order 1963 (or as amended), may be accepted for disposal but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR. Customers must have tried to return sources to the supplier or manufacturer and considered alternative uses before consigning sources for disposal. In addition, the following conditions must be met:</p> <ul style="list-style-type: none"> • Each individual source to be disposed of must not, in its raw state, exceed 1MBq total Alpha and Non Alpha activity • As much extraneous packaging and shielding must be removed from the source as possible • Sources are to be grouted into a <i>Small Container</i> and have approximately 100ml of grout surrounding each source. • The maximum number of sources to be disposed of in a <i>Small Container</i> is 150, if the 15 litre maximum size container is used. • Only one <i>Small Container</i> may be consigned within a <i>Waste Consignment</i> • For the purpose of calculating the specific activity of the Waste Consignment, the 	<p>Revised controls to be based on restricting exposures if sources were to be found on the beach following coastal erosion of the site (Subsection 6.5). Sources to be controlled based on the level of activity (Table 6.10) and with suitable conditioning (Table 6.11).</p>

Paragraph	Current WAC	Our Conclusions
	<p>weight of the grout and Small Container may be included to give the specific activity of the sources, in GBq/t</p> <ul style="list-style-type: none"> A unique Waste Characterisation Form (Reference: WSC-FOR-WCH) must be approved by LLWR for each <i>Small Container</i> disposal and include the following information: source registration references, the radionuclides, the total activity per source, any radioactive decay calculations, the number of discreet sources and the amount of grout per source in the <i>Small Container</i> 	
L3	Packaging and Transport Requirements	
L3.1	<p>Approved Disposal Containers</p> <p>Waste for disposal may be consigned to the Low Level Waste Repository in any of the approved <i>Disposal Containers</i> listed in Table 4.</p>	<p>These are included within the assumptions of the ESC (Subsection 4.1). The waste acceptance process controls variations and significant packaging changes will be kept under review (Subsection 8.1.2).</p> <p>To be retained with no changes required.</p>

Paragraph	Current WAC						Our Conclusions																																																																													
	<p>Table 4: Approved Disposal Containers</p> <table border="1"> <thead> <tr> <th data-bbox="371 296 734 323">Disposal Container Type</th> <th data-bbox="741 296 869 323">Design Ref.</th> <th data-bbox="875 296 1032 323">Historic Ref.</th> <th data-bbox="1039 296 1167 355">Column A (tonne)</th> <th data-bbox="1173 296 1301 355">Column B (tonne)</th> <th data-bbox="1308 296 1435 355">Column C (m³)</th> <th data-bbox="1442 296 1570 355">Column D (m³)</th> </tr> </thead> <tbody> <tr> <td>1/3 Height Disposal Container</td> <td>TC03</td> <td>2989</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>TC09</td> <td>2910B</td> <td>35</td> <td>42</td> <td>17.9</td> <td>19.5</td> </tr> <tr> <td>1/2 Height Disposal Container</td> <td>TC01</td> <td>2910C</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>2968</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>3550</td> <td>35</td> <td>42</td> <td>24.8</td> <td>29.7</td> </tr> <tr> <td>1/3 Height Fissile Disposal Container</td> <td>N/A</td> <td>3563</td> <td>35</td> <td>40</td> <td>11.3</td> <td>13.0</td> </tr> <tr> <td>1/2 Height Fissile Disposal Container</td> <td>N/A</td> <td>3564</td> <td>35</td> <td>42</td> <td>17.9</td> <td>19.5</td> </tr> <tr> <td>WAMAC Disposal Container</td> <td>TC07</td> <td>2947B</td> <td>35</td> <td>40</td> <td>17.9</td> <td>20.0</td> </tr> <tr> <td>WAMAC Disposal Container</td> <td>TC08</td> <td>2947C</td> <td>35</td> <td>40</td> <td>17.9</td> <td>20.0</td> </tr> <tr> <td>ISO Skip Disposal Container</td> <td>N/A</td> <td>2921B</td> <td>17</td> <td>22</td> <td>8.5</td> <td>11.4</td> </tr> </tbody> </table> <p>Notes: <i>Column A:</i> 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 (CSC) approval plate on each container and shall be checked before the container is filled with waste. <i>Column B:</i> 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 <i>Overweight Containers</i> in accordance with L3.6. <i>Column C:</i> shows the <i>Internal Volume</i> of each Disposal Container type, in m³, which is used for the purposes of calculating the maximum <i>Inaccessible Voidage</i> that may be accepted in a Disposal Container in accordance with L3.4. <i>Column D:</i> shows the <i>Package Volume</i> of each Disposal Container type, in m³, which is used for the purposes of calculating the disposal charges, independent of the actual volume of waste in the container.</p>						Disposal Container Type	Design Ref.	Historic Ref.	Column A (tonne)	Column B (tonne)	Column C (m ³)	Column D (m ³)	1/3 Height Disposal Container	TC03	2989	35	40	11.3	13.0	1/2 Height Disposal Container	TC09	2910B	35	42	17.9	19.5	1/2 Height Disposal Container	TC01	2910C	35	42	17.9	19.5	2/3 Height Disposal Container	TC06	2968	40	42	22.3	26.8	3/4 Height Disposal Container	TC04	3550	35	42	24.8	29.7	1/3 Height Fissile Disposal Container	N/A	3563	35	40	11.3	13.0	1/2 Height Fissile Disposal Container	N/A	3564	35	42	17.9	19.5	WAMAC Disposal Container	TC07	2947B	35	40	17.9	20.0	WAMAC Disposal Container	TC08	2947C	35	40	17.9	20.0	ISO Skip Disposal Container	N/A	2921B	17	22	8.5	11.4	
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L3.2	<p>Other Containers Waste that cannot be readily consigned in one of the approved <i>Disposal Containers</i>, as detailed in L3.1, may be acceptable for disposal in other containers but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) and <i>Suitable Supporting Justification</i> by LLWR.</p>						<p>The waste acceptance process will control variations and significant packaging changes will be kept under review (Subsection 8.1.2). To be retained with no changes required.</p>																																																																													
L3.3	<p>Non-Containerised Waste Non-containerised waste is not accepted for disposal at the Low Level Waste Repository.</p>						<p>Non-containerised wastes are only accepted subject to ensuring contamination and other WAC</p>																																																																													

Paragraph	Current WAC	Our Conclusions
		<p>requirements are met. These measures ensure control of potential short-term releases (Subsection 4.1).</p> <p>To be retained with no changes required.</p>
L3.4	<p>Inaccessible Voidage</p> <p>Customers are responsible for loading the <i>Disposal Container</i> so that <i>Inaccessible Voidage</i> is minimised as far as reasonably practicable and in any event shall not exceed 10% of the <i>Internal Volume</i> of the <i>Disposal Container</i>, as defined in Column C of Table 4.</p> <p>As far as reasonably practicable, any <i>Inaccessible Voidage</i> shall be uniformly distributed within the <i>Disposal Container</i>.</p>	<p>This will be combined with requirement for biodegradable and putrescible materials (paragraph L1.15) in order to meet cap performance requirements (Subsection 4.4).</p> <p>This will include the requirement to use reasonable means to limit the quantity of biodegradable materials and inaccessible voidage in the waste and that the total potential voidage from all sources does not exceed the derived cap settlement criterion (Subsection 4.4).</p>
L3.5	<p>Packing Efficiency</p> <p>Customers are responsible for loading the <i>Disposal Container</i> so that, as far as reasonably practicable, waste is packaged in such a way as to maximise the <i>Packing Efficiency</i> of the <i>Disposal Container</i>, whilst ensuring sufficient grout penetration can still be attained.</p>	<p>Required in order to conserve volumetric capacity at the LLWR. No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L3.6	<p>Overweight Containers</p> <p>Customers are responsible for loading the <i>Disposal Container</i> so that when it is filled with grout, of nominal density 1,800 kg/m³, the gross weight of the <i>Disposal Container</i> does not exceed the maximum gross weight in Column B of Table 4. Where Customers calculate or anticipate that the <i>Disposal Container</i> will exceed the maximum gross weight after grouting, the <i>Waste Consignment</i> may still be accepted but only on approval of a Waste Consignment Variation Form (Reference: WSC-FOR-WCV) by LLWR.</p>	<p>Required for operational safe handling reasons. No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L3.7	<p>Disposal Container Venting</p> <p>The <i>Disposal Container</i> shall not be left un-vented for more than thirty days in advance</p>	<p>Required for operational safety reasons associated</p>

Paragraph	Current WAC	Our Conclusions
	of delivery to the Low Level Waste Repository.	with potential pressurisation of containers by degradation gases prior to grouting; after grouting, containers are not sealed. Gaseous releases are considered in Subsections 6.3.1 and 6.3.3 for the PoA and long-term respectively. To be retained with no changes required.
L3.8	<p>Disposal Container Labelling</p> <p>Each <i>Disposal Container</i> shall be uniquely marked or labelled so as to be legible for at least five years after delivery such that the Customer and a Consignment Serial Number can be identified.</p>	Required for operational reasons. No implications from the ESC. To be retained with no changes required.
L3.9	<p>Photographic Records</p> <p>Customers are responsible for ensuring that, as far as reasonably practicable, photographic records of the step by step filling of the <i>Disposal Container</i> with waste are produced and retained by the Customer. Photographs should be taken when the <i>Waste Consignment</i> 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 WAMAC Disposal Containers.</p>	Required for quality control purposes. No implications from the ESC. To be retained with no changes required.
L3.10	<p>Transport Regulations</p> <p>Waste must be consigned for treatment or disposal in accordance with the latest edition of IAEA TS-R-1 (Safe Transport of Radioactive Material Regulations), as required by The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (or as amended) and ADR, under one of the following classifications:</p> <ul style="list-style-type: none"> • Excepted Package • Low Specific Activity material (LSA I, LSA II) • LSA III (subject to confirmation of leaching test) • Surface Contaminated Object (SCO I or SCO II) <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>	Required for compliance with Transport Regulations. No implications from the ESC. To be retained with no changes required.

Paragraph	Current WAC	Our Conclusions
	In addition, any <i>Waste Consignment</i> or <i>Disposal Container</i> 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) by LLWR.	
L3.11	<p>Transport of Fissile Radionuclides</p> <p>Waste transported in IP-2 containers may contain very low quantities or very low concentrations of <i>Fissile Radionuclides</i> when classified as Fissile Excepted Packages. In order to use the Fissile Excepted Package classification, one of the fissile exemption criteria in the Transport Regulations must be satisfied and the justification documented. Please note that the fissile excepted criteria do not always align with the criteria for <i>Fissile Radionuclides</i> in L2.3.</p> <p>Customers must contact LLWR for advice if they intend to consign waste to LLWR that contains <i>Fissile Radionuclides</i> above the fissile excepted criteria, prior to loading waste. Customers must ensure they fulfil the requirements of these Waste Acceptance Criteria and the Transport Regulations when consigning <i>Fissile Radionuclides</i> to LLWR.</p>	<p>Required for operational reasons. No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L3.12	<p>Part Loads</p> <p>A <i>Waste Consignment</i> may not be consigned to LLWR if sent as a part-load with other materials that are not <i>Low Level Waste</i> on the same vehicle.</p>	<p>Required for operational reasons. No implications from the ESC.</p> <p>To be retained with no changes required.</p>
L3.13	<p>Site Rules and Instructions</p> <p>When delivering waste to LLWR for disposal, the Customer's representatives must observe the site rules and instructions at the Low Level Waste Repository or the <i>Service Supplier's</i> site.</p>	<p>Required for operational safety reasons. No implications from the ESC.</p> <p>To be retained with no changes required.</p>

8.3 Emplacement Strategies

Work within the ESC, including that discussed in this report, has identified that emplacement strategies are necessary for certain waste streams and waste consignments. Such an approach is also good practice as part of optimisation measures to minimise the environmental impact of disposals to the LLWR.

The wastes requiring to be managed as part of emplacement strategies have been identified within this report. Based directly on the radionuclide inventory of waste streams and waste consignments (Subsection 6.4), two requirements have been identified:

- Wastes to be excluded from within 5 m of the cap surface. Such wastes as far as practicable to be placed at the lower stack positions.
- Wastes not to be co-located, in order that no more than one such consignment is placed in a single stack or adjacent to another stack with such wastes.

Two additional aspects have been identified that may require to be addressed within an emplacement strategy. Firstly, if monitoring of dose rates adjacent to the site shows a significantly increasing trend, consideration will be given to the potential role for an emplacement strategy for wastes with radiation levels significantly higher than average in order to control radiation doses from external radiation (Subsection 6.4.2). This will also take into consideration the need to limit total assessed doses, including those from gaseous releases, to be consistent with regulatory requirements. Secondly, as part of the measures to ensure doses from disposed C-14 are maintained within regulatory requirements, there may need to be controls placed on where such wastes are emplaced and to limit the nature of other wastes in such areas of the vaults (Subsection 6.3.3). Specific proposals will be developed to support both these considerations.

The ESC has also identified that in some circumstances in which non-standard consignments of wastes are accepted, waste emplacement controls will be required. These are to meet the requirements of:

- Retention of absorbed liquids based on the applied load criterion of 400 kN m⁻² if overlying consignments are of non-standard weight (Subsection 4.3).
- Maintaining potential voidage associated with wastes to within the criteria for cap settlement plus any restrictions on the emplacement of high metal content of wastes (Subsection 4.4).

The emplacement strategies for all waste consignments requiring specific management and placement within the vaults will be controlled by appropriate procedures that we will introduce. These will establish specific arrangements for the identification of all consignments requiring to be managed. They will encompass the work by the Consignor Support Team as discussed in Subsection 8.1 and also include operational stacking practices within the vaults that might otherwise cause the requirements not to be met. An example of the latter, as referred to earlier, is the emplacement of non-standard weight containers.

We have assessed the expected number of consignments that will require managing within emplacement strategies in order to ensure that it can be implemented in practice. The number of consignments expected to require emplacement restriction on the basis of the activity levels and on non-standard weight or voidage considerations is expected to be a small proportion of the total number of consignments. 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 can be used to ensure that emplacement and stacking requirements are achievable and that the requirements of the ESC in terms of waste acceptance are met.

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9 Conclusions

This report describes the results of a programme of work to identify waste acceptance criteria (WAC) and associated waste control arrangements for the LLWR on the basis of the understanding generated by the 2011 Environmental Safety Case (ESC).

In carrying out this work, emphasis has been placed on developing an approach in accordance with regulatory guidance and requirements, and to provide a tool to support LLWR site management. In deriving the approach, requirements provided by the Environment Agency in response to previous submissions and best practice guidance from relevant international bodies have also been considered.

The report identifies controls and associated WAC that are consistent with the understanding generated and requirements identified throughout the ESC. It is important that the WAC take into account the outcomes of assessments concerning the potential environmental impacts from both disposed radionuclides and non-radiological contaminants, and reflect the data and assumptions underpinning those assessments in a consistent way. Revised radiological limits have been derived on the basis of compliance with dose limits and comparison with risk and dose guidance levels set out in the Environment Agency's guidance.

The report shows how the WAC and associated waste control arrangements will provide a tool to support implementation of the following requirements throughout future LLWR operations. The approach provides for:

- Management of the radiological capacity of the LLWR, consistent with the understanding underpinning by the ESC and relevant Permit conditions.
- Application of additional consignment limits to control activity concentrations.
- For those wastes that are of the greatest potential significance in environmental safety terms, additional emphasis is placed on ensuring that the approach to disposal represents the use of BAT for the management of the wastes.
- The use of an emplacement strategies for particular waste streams and waste consignments where specific arrangements are required to demonstrate optimisation with respect to environmental safety.
- Provision of a basis for revisions to the WAC and the waste acceptance arrangements that incorporate the assumptions and findings of the ESC.

On completion of the 2011 ESC, we will take forward the finalisation of the revised WAC and waste control arrangements.

In summary, the basis for revised waste control arrangements has been systematically developed, based on the results of the 2011 ESC, and consistent with regulatory guidance and requirements. The implementation of these arrangements will provide a basis for ensuring the environmental safety of the site in both its operational phase and in the longer-term.

It is intended that the approach to implementation will be the subject of engagement with the Environment Agency and will include considerations necessary to ensure compliance with the Permit for the site.

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Appendix 1: List of Acronyms

ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
ALARA	As low as reasonably achievable
BAT	Best Available Techniques
BNFL	British Nuclear Fuels Limited
BPEO	Best Practicable Environmental Option
BPM	Best Practicable Means
Defra	Department for Environment, Food and Rural Affairs
GRA	Guidance on Requirements for Authorisation for Near-Surface Disposal Facilities on Land for Solid Radioactive Wastes
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ISO	International Organization for Standardization
LLW	Low-level waste
LLWR	Low Level Waste Repository
NAPL	Non-aqueous Phase Liquids
NDA	Nuclear Decommissioning Authority
PEG	Potentially Exposed Groups
PoA	Period of Authorisation
SLC	Site Licence Company
UKRWI	UK Radioactive Waste Inventory
WAC	Waste Acceptance Criteria
WAMAC	Waste Monitoring and Compaction Plant
WIDRAM	Waste Inventory Disposition Route Assessment Model