LLW Repository Ltd

Environmental Safety Case

Technical Approach to the 2021 Environmental Safety Case

LLWR/ESC/R(16)10073 Issue 2

March 2016

	Name	Signature	Date
Author	AJ Baker		06.04.16
Checker	T Sumerling	Trevor Sumerling	06.04.16
ESC Technical Integrator	AJ Baker		06.04.16
Approver	R Cummings		06.04.16

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Executive Summary

The Low Level Waste Repository (LLWR) at Drigg is the United Kingdom's principal facility for the disposal of Low-level Waste (LLW). The site is owned by the Nuclear Decommissioning Authority (NDA) and operated on behalf of the NDA by a Site Licence Company, LLW Repository Ltd.

The disposal of radioactive waste at or from the LLWR is regulated by the Environment Agency. LLW Repository Ltd submitted a fully revised Environmental Safety Case (ESC) to the Environment Agency in May 2011 (the 2011 ESC) and subsequently this has been reviewed by the Environment Agency. As an output of the review, the Environment Agency identified a number of Forward Issues (FIs) and recommendations. Taking account of feedback and discussions with the Environment Agency, LLW Repository Ltd submitted an application for a variation to its Permit in October 2013. A new Permit was issued in November 2015. An improvement condition in the Permit requires submission of a revised ESC by May 2021, which we term 'the 2021 ESC'.

This document describes our proposed technical approach to the 2021 ESC. In parallel, we are producing a Technical Development Programme, which describes the specific activities and schedule needed to achieve the approach set out in this document. In the near future, we will also produce an Engineering Plan that describes the engineering tasks needed to refine and substantiate our engineering design. Together these documents:

- set out a forward programme of work required to deliver the 2021 ESC and to construct the necessary engineered barriers and components;
- address the Permit requirement to produce a forward programme;
- set out the work required to address the FIs and recommendations, except where that work has already been completed.

Key developments that are planned in or prior to the 2021 ESC include:

- consideration of a wider range of safety arguments including arguments based on additional lines of reasoning;
- a revised Features Events and Processes and Uncertainty Tracker, focusing on the provision of a record of the uncertainties and biases that need to be managed;
- some additional ESC documentation covering uncertainty, safety functions and additional and complementary safety arguments;
- an Assessment Manual setting out a more formal basis for our assessment approach;
- presentation of top levels of the ESC, drawing on web-based and visualisation approaches;
- an investigation of variability in the near field based on a numerical model on the scale of a few half-height ISO containers and other numerical models as required;
- an investigation of the effect of exchange of gas between the repository and the atmosphere on the achievement of reducing conditions in the repository;

- consideration and possible development of new modelling tools that could be used to represent the bulk chemical evolution of and gas generation within the repository;
- consideration and possible development of a programme of experimental work to build confidence in our treatment of the unsaturated zone;
- an approach to a safety functions analysis in which the safety functions of each barrier will be identified and evaluated;
- a more formally documented approach to the treatment of uncertainties and biases;
- an improved approach to treating inventory uncertainty;
- revision of the conceptual model for coastal erosion, updating the range of projected sequences for erosion, and an improved assessment model to assess the radiological impacts of coastal erosion;
- revised assessment models to assess radiological impacts during the Period of Authorisation (PoA);
- an Engineering Performance Assessment;
- revised calculations of non-radiological impact;
- a single systems assessment model for the groundwater pathway, covering the PoA and the period thereafter;
- creation and implementation of a Requirements Management System for the engineered design;
- completion of a containment Best Available Techniques study;
- setting out a more developed view of long-term monitoring and institutional control;
- systematic consideration of the implications of different sorts of spatial variability in the assessments.

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1 Introduction

1.1 Background

The Low Level Waste Repository (LLWR) at Drigg is the United Kingdom's principal facility for the disposal of Low-level Waste (LLW). The site is owned by the Nuclear Decommissioning Authority (NDA) and operated on behalf of the NDA by a Site Licence Company, LLW Repository Ltd. The LLWR is managed as an efficient and environmentally safe facility for the disposal of LLW in the UK. This is achieved in accord with best technical practice for the near-surface disposal of radioactive waste, in compliance with applicable environmental and health and safety legislation, in accord with regulatory guidance and in compliance with the terms of the Permit under which we operate.

The disposal of radioactive waste at or from the LLWR is regulated by the Environment Agency. Prior to November 2015, LLW Repository Ltd held a Permit [1] under the Environmental Permitting Regulations allowing it to dispose of and transfer radioactive wastes. This Permit was a variation on an Authorisation issued under previous legislation on 1st May 2006, and was based on the Environment Agency's review and consideration of safety cases prepared by the previous site operator [2,3].

LLW Repository Ltd submitted a fully revised Environmental Safety Case (ESC) to the Environment Agency in May 2011 (the 2011 ESC) [4]. This was in response to a condition in the LLWR's Permit. Subsequently, the Environment Agency undertook a review of the 2011 ESC [5,6,7,8,9,10,11,12]. As an output of the review, the Environment Agency identified a number of Forward Issues (FIs) and recommendations. Taking account of feedback and discussions with the Environment Agency, LLW Repository Ltd submitted an application for a variation to its Permit in October 2013 [13,14]. A new Permit was issued in November 2015 [15].

One of the improvement conditions (IC7) in the new Permit is that the LLWR should:

'submit an update to the environmental safety case for the site based upon a comprehensive review, covering the full life-cycle of the facility. The review shall demonstrate that all the requirements of the latest version of the environment agencies' guidance on requirements for authorisation for near-surface disposal facilities on land for solid radioactive waste have been met. The review shall address the findings of the Environment Agency's review of the 2011 ESC.'

Such submission is required by May 2021. We term this ESC the '2021 ESC', noting that the Environment Agency has indicated that there is flexibility to vary this deadline, depending upon the timescales of developments at the LLWR.

The Permit also sets out an improvement condition (IC4) that the LLWR should:

'Submit a written plan to the Environment Agency. The plan must contain the operator's comprehensive forward programme of work to support the environmental safety case. The plan should address, but not necessarily be limited to:

- *The Environment Agency's review of the 2011 environmental safety case.*
- *Conditions and limits in this permit.*
- *Learning from development and implementation of the 2002 and 2011*

environmental safety cases.

- *Monitoring Data.*
- *Uncertainties identified within the environmental safety case.*
- *Peer review comments on the environmental safety case.*

The plan must be implemented unless otherwise agreed in writing by the Environment Agency.'

Similarly, in one of the FIs [11], ESC-FI-004, the Environment Agency set out a requirement to:

'*... further develop and update its forward programme of work to make sure that there is continued improvement of the ESC.*'

The Environment Agency expects the LLW Repository Ltd to develop and update its forward programme, systematically taking account of their completed review of the 2011 ESC, and associated FIs and recommendations. We are required to respond formally to each FI and we have put in place a mechanism to track our responses to recommendations.

We have set out a proposed '*Technical Approach to the 2021 ESC*' in this document. This document is the successor to the '*Technical Approach to the 2011 ESC*' [16]. In parallel to the technical approach, we are producing a Technical Development Programme to deliver the ESC [17], which describes the specific activities and schedule needed to achieve the approach set out in this document. We also intend to produce during this calendar year an Engineering Plan that describes the engineering tasks needed to refine and substantiate our engineering design. Together these documents:

- set out a forward programme of work required to deliver the 2021 ESC and to construct the necessary engineered barriers and components;
- address permit requirement IC4 to produce a forward programme;
- set out the work required to address the FIs and recommendations, except where that work has already been completed.

This report has been revised following comments from the LLWR’s ESC Peer Review Group (PRG).

1.2 Approach

We have developed the 2021 ESC Plan on the basis of a number of sources of information. These include:

- the Environment Agency's FIs and recommendations arising from their review of the 2011 ESC;
- the recent Annual (being drafted) and Periodic [18] Reviews of the ESC;
- the most recent report of the PRG [19] and underlying document specific reviews;
- key uncertainties in the 2011 ESC as identified in the Features Events and Processes (FEP) and Uncertainty Tracker [20];
- the outcome of workshops on the near field [21] and on assessments [22], involving contractors and LLWR staff;

- an uncertainty and bias audit of the near field and supporting technical work [23,24,25,26,27];
- ESC team workshops covering various technical areas.

All of these sources have been considered in developing a plan for the ESC that we consider is proportionate, achievable in the available time and which addresses key needs and improvements.

1.3 Scope

The ESC is designed to satisfy the requirements of the Environment Agency as set out in the *Guidance on Requirements for Authorisation for Near-surface Disposal Facilities on Land for Solid Radioactive Wastes* (NS-GRA) [28]. The NS-GRA sets a fundamental protection objective:

'to ensure that all disposals of solid radioactive waste to facilities on land are made in a way that safeguards the interests of people and the environment now and in the future, commands public confidence and is cost-effective.'

This document does not address any regulatory requirements of the Office for Nuclear Regulation (ONR), including any pertaining to operational health and safety. Aspects related to ecological, visual or other planning-related requirements are also outside the scope of this document as they are addressed in other parts of the LLWR's programme.

The report does not address engineering design activities in full, but makes cross-reference where appropriate and addresses interface aspects. Such activities are addressed in a separate Engineering Plan, which is in preparation.

The technical approach set out in this document represents our current views. Of course, these views may change as a result of new information, including that derived from our Technical Development Programme, or comment from external parties such as the Environment Agency and the PRG. In general, our overall approach will be similar to that in the 2011 ESC. Many of the same arguments and models will be used. In this document, we focus on describing the changes and enhancements rather than reiterating aspects of our approach from the 2011 ESC that will only be updated.

This document assumes that the LLWR will continue to be used only for the disposal of LLW. Any changes to this assumption would require review and revision of the technical approach set out here, and the associated Technical Development Programme,

1.4 Addressing regulatory requirements

A key objective of the 2021 ESC will be to demonstrate compliance with the regulatory requirements in the NS-GRA. In Table 1.1, the material in this report is matched to the 14 requirements (R1 to R14) in NS-GRA. A broader discussion, setting out the basis on which we will meet the requirements, is provided below and a route map is provided to where work to address these requirements is described.

R1 concerns the creation of a voluntary agreement between the operator and the Environment Agency. This requirement is directed at the early stage of repository development, whereas the LLWR has been a facility for the disposal of radioactive waste since 1959. The Environment Agency has a locus for regulatory action under the current Permit, so the requirement is of limited relevance to the LLWR.

R2 indicates that the developer should take the lead in dialogue with the potential host community, other interested parties and the general public. The LLWR has an active programme of stakeholder engagement that addresses this requirement. A commentary is provided in Subsection 2.3.

R3 requires an application for the disposal of radioactive waste to be supported by an ESC. An ESC is:

'a set of claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence.'

Section 2 sets out our approach to producing an ESC.

R4 requires that we should foster a positive environmental safety culture and possess a management system, organisational structure and resources sufficient to provide the necessary management, safety and quality functions. This is delivered through the LLWR management system [29], and also our Environment, Health, Safety and Quality (EHS&Q) Policy as summarised in Subsection 2.5.

R5 sets out the dose constraint, applicable during the Period of Authorisation (PoA), noting that supplementary guidance has set a dose limit of 20 μSv y^{-1} related to the protection of groundwater [30], R6 the risk guidance level after the period of authorisation and R7 the dose guidance range appropriate to human intrusion. Our safety assessment methodology is set out in Section 5.

R8 sets the requirement for optimisation of radiological risks. As noted in the NS-GRA, optimisation is about finding the best way forward where many different considerations need to be balanced. Our approach to optimisation is set out in Section 4.

R9 points to the need for an assessment to show that radiological impacts on the accessible environment are acceptably low. We will address this through quantitative assessment of impacts on non-human biota and also consider comparisons of levels of radioactivity arising from the facility and those present naturally as set out in Subsection 5.11.

R10 concerns an assessment of non-radiological hazards. Our proposed approach, which has recently been the subject of dialogue with the Environment Agency, is set out in Subsection 5.10.

R11 requires a programme of site investigation and characterisation to provide information for the environmental safety case and to support facility design and construction. An extensive programme of site characterisation has been undertaken leading to a good geological and hydrogeological understanding of the site (see for example reference [31]). This aspect is discussed in Subsection 3.3.

R12 requires 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. This requirement covers a number of issues related to appropriate characteristics of the design and the use of appropriate construction techniques and methodologies. These questions are closely linked to the questions of design optimisation discussed in Section 4. As part of the ESC, we will present or reference information on the approach to engineering design and how we have addressed each of the specific aspects identified under R12.

The LLWR has waste acceptance criteria (WAC) that govern the receipt of wastes at the site, consistent with R13. The WAC are consistent with the limits set out in the LLWR's current Permit and with the 2011 ESC. As an output of the 2021 ESC, we shall set out updated radiological capacities. An updated understanding of performance will also be used to identify any changes required to waste acceptance, e.g. in relation to the non-radiological component of the wastes. Our approach is set out in Section 6.

R14 sets out the need for a programme of monitoring. The LLWR reports annually on our monitoring programme [32]. As part of the ESC, we will describe the programme of monitoring, demonstrate that it is appropriate and indicate how it has been used as input to the safety assessment or in building confidence in the approach that we have used. We will also provide a fuller description of our approach to long-term monitoring. These aspects are covered in Subsection 2.4.

We will remain aware of and address any changes to regulatory guidance, in particular in relation to any update of the environment agencies' guidance on the near-surface disposal of radioactive waste.

Table 1.1 Addressing the requirements in the regulatory guidance

Requirement	Approach	Subsection Cross-reference
R1 Process by Agreement	This requirement is directed at the early stage of repository development, whereas the LLWR has been a facility for the disposal of radioactive waste since 1959. It is therefore not of direct relevance to the LLWR.	-
R2 Dialogue with local communities and others	The LLWR has an active programme of stakeholder engagement that addresses this requirement.	2.3
R3 Environmental Safety Case	The present document describes the proposed technical approach to delivering an ESC.	2
R4 Environmental safety culture and management system	We are committed to the protection of the environment and health and safety of both workers and members of the public, now and in the future. The commitment is formalised in our EHS&Q Policy	2.5
R5 Dose constraints during the period of authorisation	The site will be monitored during the operational period and if observations warrant this, actions will be taken to reduce discharges. We will use simple modelling approaches to determine potential releases during the operational period – to complement the information obtained from monitoring and to demonstrate that we are developing a consistent understanding of the performance of the facility.	5.2
R6 Risk guidance level after the period of authorisation	A range of calculations will be undertaken to estimate the risks arising from a range of scenarios and cases taking account of a broad range of uncertainties.	5

Table 1.1 (continued)

Requirement	Approach	Subsection Cross-reference
R7 Human intrusion after the period of authorisation	The radiation doses will be assessed for a range of human intrusion events based on those defined in the 2011 ESC.	5.9
R8 Optimisation	A range of options assessments have been or will be undertaken to address the key questions about the use of the site, facility design and management of the site and facility.	4
R9 Environmental radioactivity	Radiological impacts to non-human species will be estimated using the ERICA approach. We will also compare levels of radioactivity arising from the facility with naturally occurring levels of radioactivity.	5.11
R10 Protection against non-radiological hazards	Calculations will be undertaken using an approach as closely aligned to the approach for radioactive contaminants as is possible. These will be used to assess the extent to which the facility provides adequate protection against non-radiological hazards.	5.10
R11 Site investigation	We have carried out an extensive programme of site characterisation and we continue to monitor the site and its environs. The programme of site characterisation, the resulting conceptual models and data and their use in the safety assessment will be described in the ESC.	3.3 & 3.4
R12 Use of the site and facility design, construction, operation and closure	In the ESC, the reasons for the choice of design and its suitability will be discussed. This will cover the work undertaken on optimisation and reference will also be made to the various engineering studies undertaken.	4
R13 Waste acceptance criteria	WAC have been defined and will be updated as needed, consistent with the ESC and our latest understanding of the safety of the repository and any updated Permit.	6
R14 Monitoring	We have an integrated, extensive and ongoing programme of monitoring. This will be presented as part of the ESC.	2.4

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2 The Environmental Safety Case

In this section, we describe some of the key safety arguments or approaches that we propose to use in presenting the 2021 ESC. Optimisation is a very important part of our approach and is addressed in Section 4 of this report.

2.1 Overview

Requirement R3 of the NS-GRA [28] states:

"An application under RSA 93 relating to a proposed disposal of solid radioactive waste should be supported by an environmental safety case."

Supporting text defines an ESC as:

"a set of claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence"

and further states that the ESC should be designed to show that the management, radiological and technical requirements (i.e. Requirements 5 to 14 of the NS-GRA) are met. Further guidance on the ESC is provided in Chapter 7 of the NS-GRA.

Our approach to addressing the 14 requirements in the NS-GRA is summarised in Table 1.1, which also provides a link to sections of this document.

We propose to continue to present the ESC around a set of key safety arguments, for which we will provide supporting evidence.

The development of the ESC is an iterative and ongoing process. Building on an established base, it involves progressive development and focused improvement of data, understanding, design options and assessments. The development must integrate information from a wide range of technical studies, as well as non-technical inputs and decisions. A key development since the 2011 ESC has been the implementation of the ESC as a live safety case. This means that it is regularly reviewed and updated to reflect any significant changes to data or plans. Further, it is used to make decisions on design and waste acceptance. There is now an established process by which the ESC is reviewed and updated and new information and plans are logged and considered [33]. Outputs from the Periodic and Annual Reviews have been considered in developing the technical approach described in this report.

2.2 Safety functions

The NS-GRA indicates (paragraph 7.2.1) that the ESC needs to show how the various components of the disposal system contribute to meeting the requirements. In the 2011 ESC, we set out some safety functions for each barrier, presented an understanding of the evolution of each barrier and undertook certain calculations to characterise the function of each barrier.

As part of the 2021 ESC, we will present a more developed approach to defining and demonstrating safety functions for the barriers that are expected to contribute to the safety of the LLWR over its operating and post-closure lifetime. This will involve describing the main safety functions for each barrier and setting out a conceptual model for the evolution of the barrier in terms of the features and processes relevant to that barrier. There will also be a need to acquire relevant data and to develop confidence in conceptual and numerical models. Where useful insight may be obtained, we will undertake specific calculations to indicate the estimated performance of each barrier, for example, in containing or retarding contaminants. It is noted that the performance of barriers may change as a function of time because of degradation of the barrier and in addition different barriers may be relevant on different timescales. Although we intend to develop a comprehensive safety functions approach, we do not propose to structure the whole of the presentation of the 2021 ESC around safety functions.

We envisage that we will present an additional report as part of the ESC document suite focused on safety functions and the additional line of argument that they provide concerning the design and safety of the LLWR facility (see Subsection 2.7.1). The additional report would enable material and evidence about each barrier to be drawn together and presented in a coherent manner rather than for information to be distributed.

There is a strong link with two planned activities in the Technical Development and Engineering Programmes. First, the Engineering Performance Assessment (EPA) described in Subsection 3.2.4 will provide important inputs. Secondly the Requirements Management System (RMS) that we propose to implement for the engineering design will set out the safety functions of each barrier and relate these to detailed design requirements (see Subsection 4.3).

2.3 Stakeholder engagement

In reaching a view about the use, management and operation of the site, consultation with stakeholders is key. Our stakeholders include:

- local residents;
- councils at the parish, district and county level;
- unions and employees;
- regulators such as the Environment Agency and the ONR;
- the Nuclear Legacy Advisory Forum (Nuleaf);
- the West Cumbria Sites Stakeholder Group (WCSSG) and its LLW Working Group;
- waste consignors;
- national Government;
- the technical community, including our contractors.

We are committed to regular engagement with stakeholders on all LLWR matters, for example the WCSSG LLWR Subcommittee has received presentations on issues specifically relating to repository operations and supporting work, including the ESC. Regular interface meetings are held involving the Environment Agency, the ONR and the NDA. Quarterly liaison meetings take place between the LLW Repository Ltd and Drigg and Carleton Parish Council, affording the opportunity for any concerns to be raised and addressed. This forum is also used to provide an update on current operations and projects and to discuss future plans for the Repository. Consignors have open access to a LLWR team and meetings are arranged to address specific issues. In addition, a Consignors' Forum is arranged on an annual basis. We are committed to continuing stakeholder engagement as part of future work.

As part of the ESC, we will develop a document that provides an accessible summary of the work that we have done and the results. This will be as non-technical as possible in content and therefore potentially suitable to inform a wide range of stakeholders including local residents and councillors. In contrast to the 2011 ESC, we are planning that this material should be a web document that might be hyperlinked to visual presentations of site evolution, progressive construction and impacts as well as to appropriate reference material. The objective of such work is to better communicate the ESC to non-technical stakeholders. This approach is discussed further in Subsection 2.7.2.

As for the 2011 ESC and 2013 Permit Application, we are also planning to place reports relevant to the 2021 ESC and the supporting programme of work on the LLWR's website.

2.4 Monitoring

We regard monitoring data as an important basis for the ESC. As part of the 2021 ESC, we will set out a series of arguments on the basis of monitoring data. In general, these arguments will be similar to those set out in the 2011 ESC [44]. In presenting the monitoring programme, we will focus on geological, hydrogeological, climate, contaminant transport and coastal process aspects, noting that activities related to landscape, habitats and ecology are mostly addressed outside the LLWR's ESC programme.

The Environment Agency has identified a FI (ESC-FI-005) [11], which requires the use of monitoring to reduce uncertainties in the ESC. We are committed to using monitoring data to reduce uncertainties where this is possible and will explain our detailed arguments in future documentation, notably the Level 2 Monitoring Report (see Subsection 2.7.1) that we would produce as part of the 2021 ESC. We note that monitoring data can be used in a number of ways, for example for calibration, to demonstrate that models are cautious, to build confidence in the models or to inform a view on parameter values.

We envisage presenting on the following aspects in the 2021 ESC:

- a strategy for long-term monitoring of the Repository;
- a demonstration that our monitoring programme is integrated with, and takes account of, our developing engineering design, and showing how our design makes provision for monitoring[1];
- a focus on the monitoring of changes to the engineered barriers including the repository cap;
- data on organic complexants that might impact on contaminant transport;
- activity that might be associated with particulate material in trench leachate to inform a more developed view on potential colloidal transport of contaminants;
- our coastal evolution monitoring programme;

[1] It is noted that Construction Quality Assurance (CQA) is a powerful auditing tool to ensure that the implementation of engineering is achieved to the standard of the design. This is a standard part of our approach and is within the remit of the Engineering Plan.

- the outcome of a watching brief on the development of understanding long-term changes in storminess associated with climate change, as well as the frequency and magnitude of storm surge events.

We will continue the collection of hydrological and hydrogeological data to support future refinements of the ESC hydrogeological models and engineering design with the aim of reducing uncertainties in the ESC. We will specifically consider whether any additional data need to be acquired to fill any data gaps. Data on the distribution of tritium in the trenches and groundwater will continue to be collected and will be considered in establishing requirements for future monitoring infrastructure. Available data on the distribution of tritium will inform a view on current contaminant transport pathways and link with work that we have recently undertaken on the detailed geological structure of the B2 unit and its influence on groundwater flow [34]. Tritium data need to be considered when evaluating numerical models of the site in that numerical models should be consistent with the observations, taking account of issues such as variability.

An annual report, providing a description and interpretation of the entire environmental monitoring programme undertaken each year, will continue to be produced throughout the period before the next ESC, to show how the monitoring results have been used to inform decisions on risk management options for the site (e.g. in relation to the management of the interim trench cap [35]) and build confidence in the safety assessment models that underpin the ESC.

We will continue to use monitoring data in the calibration of future hydrogeological models and clearly substantiate the choice of parameters and data ranges used. We also envisage using monitoring data on concentrations on non-radiological contaminants as a basis for impact modelling where no estimate of the disposed inventory is available.

We acknowledge that consideration needs to be given to the decommissioning of old boreholes. LLWR has procedures in place for decommissioning boreholes in line with Environment Agency guidance to prevent the creation of potential pollutant pathways. There is the potential for a small number of old boreholes to be lost and for these we would seek to demonstrate using simple quantitative arguments that there is no undue effect on repository performance.

2.5 Environmental safety culture and management system

As part of the ESC, we will set out relevant arguments that will be similar to those in the 2011 ESC:

‘*We have a sound Management System, a positive safety culture and are committed to high standards of environmental safety and quality, as formalised in our Environment, Health, Safety and Quality Policy.*’

‘*Our ESC Project is managed under our Management System. We have carried out our programme of work for the ESC Project according to an ordered plan that provides appropriate, accurate and timely information and results to support decision-making at each stage of development of the ESC. The ESC Project team interacts with other LLWR teams to ensure the consistency of the ESC with other LLWR activities and to ensure other activities are aligned to meet the requirements and needs of the ESC.*’

We propose to make similar arguments, updating them to reflect improved approaches and documentation, e.g. our revised Management System [29]. LLW Repository Ltd has a suite of EHS&Q arrangements, which are continually being developed and maintained to give continual improvement. Changes to the management system are, and will continue to be, subject to the Nuclear Site Licence Conditions due processes including, where appropriate, arrangements made under Nuclear Site Licence condition 36 'Control of Organisational Change' and the Environmental Permitting Regulations. Any changes to the management arrangements affecting the requirements of the Nuclear Site Licence or Permit would be subject to consultation and due process with the ONR and the Environment Agency, as appropriate.

The development and implementation of the ESC is now governed by a Repository Site Procedure [33]. Amongst other things, this requires that new information relevant to the ESC is evaluated. Annual and Periodic Reviews are required, the latter every three years. The first example of a Periodic Review has recently been completed [18]; the first Annual Review is being drafted. A track record has been established in terms of identifying and evaluating new information. The management of the ESC as a live safety case will be an important element in our safety case.

It is important that we remain abreast of developments in repository design and assessment. Our objective is to achieve this by liaison with other programmes and by participating in relevant national and international workshops and conferences.

2.6 Safety arguments

The 2021 ESC will present the structured arguments and evidence concerning the environmental safety of disposals of solid radioactive waste at the LLWR as required by the NS-GRA (see Subsection 2.1). Many of these arguments will be those set out in Section 4 of the 2011 ESC Main Report [4]. However, we will review and reconsider those arguments and it is likely that we will present additional arguments.

We note that monitoring data are able to provide independent evidence for the performance of the facility up to the present and in the near future. Monitoring data are used as an input to estimates of radiological impact during the PoA. However, it is sometimes difficult to use monitoring data to support a view on performance in the future as the system will evolve over time and its behaviour may change. Of course, monitoring data can be used to assess whether the repository system is developing as anticipated and whether any models or assumptions require revision.

It is difficult to identify arguments that might provide a completely independent view of system performance in the sense that an independent estimate of impact can be obtained. However, there are a number of complementary arguments that might be informative, such as those related to:

- comparisons with the behaviour of natural radioactivity in the environment;
- comparisons between the radiological impact of the LLWR and that in Cumbria from natural and other anthropogenic sources;
- arguments concerning the performance of each barrier and the provision of safety functions that operate in complementary fashion over different stages during the development and post-closure evolution of the disposal facility;
- optimisation arguments - effectively arguments that engineering choices are made to take efficient and best advantage of the natural features of the site;

- arguments concerning releases of activity into coastal environments at other locations.

As part of the Technical Development Programme, we are planning a review of independent and alternative arguments and will draw on that review in setting out arguments in the 2021 ESC.

2.7 Presentation

For the 2021 ESC, we propose to:

- adopt the 2011 ESC document structure with some enhancements (see Subsection 2.7.1);
- to take steps towards presenting at least the top-level part of the ESC in a more accessible manner, using web-based presentations (Subsection 2.7.2).

2.7.1 Document structure

The top-level document structure for the ESC is reproduced in Figure 2.1 with further details in the following table.

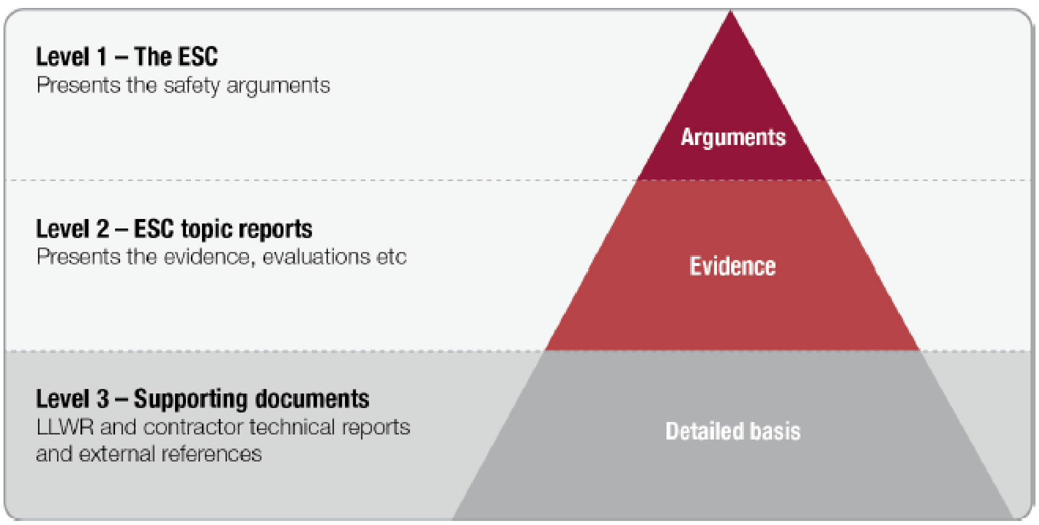

Figure 2.1 The ESC documentation concept

Level 1	
The 2011 Environmental Safety Case – Main Report [36]	
Level 2	
Management and dialogue	Management and Dialogue [37]
System characterisation and understanding	Site History and Description [38] Inventory [39] Engineering Design [40] Near Field [41] Hydrogeology [42] Site Evolution [43] Monitoring [44]
Optimisation and Site Development Plan	Optimisation and Development Plan [45]
Assessments	Environmental Safety During the Period of Authorisation [46] Assessment of Long-term Radiological Impacts [47][2] Assessment of Non-radiological Impacts [48] Assessment of Impacts on Non-human Biota [49] Waste Acceptance [50] Assessment of an Extended Disposal Area [51]
Audit	Addressing the GRA [52]

In the 2021 ESC, we have identified of the need for additional documentation, some of which might be new Level 2 ESC reports and others of which might be important Level 3 reports:

- documentation setting out our understanding of the safety functions and quantitative performance of each barrier;
- documentation setting out our approach to the management of uncertainties through the development of a live register of key uncertainties, treating the uncertainties in assessments, undertaking work to resolve them and/or developing a clear forward strategy for managing the uncertainty;

[2] In the context of this document, 'long-term' describes the period after the end of the PoA and includes the expected time of coastal erosion.

- documentation setting out alternative or complementary supporting arguments, e.g. related to monitoring and comparison with naturally-occurring radioactivity in the vicinity;
- an 'Assessment Manual' will provide a guide and summary to the assessment approach covering such aspects as uncertainty, variability, model development, program verification, model development, data management and barrier functions analysis. The Assessment Manual will be comprehensive, concise and practicable to implement. It will provide an important formal basis for undertaking assessments.

We also plan to provide more information on optimisation and the interactions between the ESC team and the engineering design team. This will include reporting of the RMS (see Subsection 4.3), which would be documented in a Level 2 or Level 3 report.

In the 2011 ESC, we developed conceptual model reports for hydrogeology and the near field and propose to update those reports as part of the 2021 ESC. We are considering the value of additional conceptual model reports covering coastal erosion and the engineered barriers (the latter linked to the EPA, see Subsection 3.2.4).

2.7.2 Enhanced approaches to presentation

We believe that it is timely to consider improved ways of presenting the ESC. We envisage that this might include:

- providing a top-level presentation in a suitable web format;
- hyperlinking the text to references and more specific explanations;
- using 3-D and other visualisation tools to represent the evolution of the site (both in terms of natural processes and construction) and pathways by which impacts might arise;
- providing an interactive component to allow alternative situations or parameter choices to be evaluated.

The objective would be to provide a version of the ESC that would be more accessible to people who are not technical experts. This initial implementation may be limited in scope, but would provide a basis for a fuller implementation of such approaches in future ESCs. An important aspect would be to draw on previous attempts at communicating safety assessments.

3 System Description and Understanding

In this section, the approach used to understand the behaviour of each component of the repository system is described. We describe our approach, the current status and the direction of future work.

3.1 Wastes and inventory

To derive the inventory for assessment, we propose to use a similar approach to that in the 2011 ESC. We intend to first transfer the legacy data from the current databases into a new system. A methodology for the derivation of the disposed inventory to use in the assessment from the new system will be developed and implemented. It is expected that the following enhancements will be made to the derived inventory:

- the improvement of data for Vault 8 by supplementing the electronic records with information from the paper records and undertaking a review of data, addressing accuracy and completeness;
- better estimates of the disposed inventory of non-radiological contaminants.

We will derive the forward inventory for the 2021 ESC using a similar approach to that used in the 2011 ESC, although on the basis of a new and more flexible inventory processing tool. It is expected that the new inventory tool will be developed to enable uncertainty in the inventory to be further explored and represented in the calculations. We expect to be able to consider the implications of differing timings of waste arising, such as accelerated decommissioning, and the impact this has on material composition assumed for the wastes and their distributions in the repository and, hence, on the results of the assessment calculations. LLW Repository Ltd is also implementing a new waste tracking and capacity management system. It is expected that the new inventory tool will be able to interface with the tracking system so that we can explore the effect of inventory uncertainty on the capacity usage of the site.

We will give consideration to the treatment in assessments of uncertainty in the inventory. It is noted that the volume of the repository would vary with the volume of the inventory and the treatment would need to consider this aspect. A priority is to further investigate the range of waste arisings that might occur in the future and to explore the implications.

Currently, the UK Radioactive Waste Inventory (UKRWI) is revised every three years. The next update is being completed for 2016. The following update is anticipated to be in 2019, with the results published in 2020, too late for use in the full assessment calculations for the 2021 ESC. We intend to use the 2016 UKWRI as the basis for the main assessment calculations in the 2021 ESC, with a review being undertaken of the likely effects on the results of the assessment calculations of the revised 2019 UKRWI.

The inventory of future wastes assumed in the 2021 ESC will reflect up-to-date information on rates of waste diversion and treatment and explore uncertainties in future rates.

We have considered further enhancements to the disposed inventory in the trenches, but consider that benefits would be low, given the extensive work undertaken prior to the last ESC [53,54,55]. The trench inventory used in the 2011 ESC was partly derived using later waste stream ‘fingerprints’. It has been suggested [56] that any revisions to the later waste stream fingerprints should be reviewed to see if they would be likely to give an improved trench inventory. This activity would involve considerable effort, including detailed discussions with consignors over the reasons for change to the fingerprints of many waste streams. Given that changes to fingerprints are most likely to result from changes in the nature of operations at individual facilities, rather than improvements in accuracy, we do not consider the benefits of such a review to be proportionate to the effort required to undertake the review.

We will develop databases for the management of legacy data for Vault 8 and the trenches. It is likely that the new waste tracking system will be used for the Vault 8 data. This will ensure that data on disposed wastes are stored within a new electronic system that is sustainable and maintainable. There are uncertainties associated with future waste arisings reported in the UKRWI, noting that waste receipts appear to be lower than would be predicted by the UKRWI. LLWR will continue to actively review other available data such as the NDA Waste Inventory Form (WIF) and actuals (e.g. disposed waste) information in order to achieve a better understanding of the forward disposal inventory.

We have undertaken work recently directed at improving the inventory of non-radiological contaminants. This has included discussions with the NDA to determine an improved approach to data acquisition in future iterations of the UKRWI. We have also reviewed and slightly expanded the list of potential contaminants of interest and are considering improved ways of seeking information from consignors. We will continue to work with the NDA and consignors to achieve further improvements in our understanding of the inventory of non-radiological contaminants.

3.2 Near field

The near field consists of the waste, engineered barriers (including grout, waste containers, vault slabs and walls, cap and cut-off walls) and immediately surrounding host geology perturbed by the construction and presence of the engineered barriers. Within this domain it is important to understand a range of processes that affect the leaching and mobility of contaminants from the waste and the resulting evolution of conditions over time. The range of processes and our current conceptual model are described in a Level 2 report [41]. This understanding will be updated before the 2021 ESC and an overview provided in a conceptual model report.

3.2.1 Modelling

In the 2011 ESC, the main tool used to understand the bio-geochemical evolution of the near field and the generation of gas was GRM [57,58]. Since that time, we have revised our treatment of the generation of C-14 bearing gas [59]. However, GRM is still important in understanding the evolution of pH, Eh and the generation of bulk gases. We may still use GRM to undertake a similar role in the 2021 ESC. However, we are undertaking a review of geochemical models and programs and may change our approach. Our approaches might include the use of programs already available in the market or the creation of a new tool, as well as continued use of GRM. The motivation would be to develop and use a technically-suitable program that would be available for long-term use in the LLWR's ESC with appropriate provision for maintenance and use by the LLWR and our contractor team. Of course, it is important to give consideration to the verification and validation of any program and this will be done.

Our overall strategy for investigating the near field would involve the use of a number of programs to investigate different aspects of the near field. For example, QPAC has been used to model chemical and transport processes associated with cracks [60] and TOUGH2 has been used to study the migration of gas and the oxygen budget of the vaults [26]. This varied approach will continue. We also note the scope for using multiple models to gain insights into different processes and their interactions and to investigate modelling uncertainty.

3.2.2 Variability

The near field is heterogeneous in a number of respects, yet in the assessment it is treated as a largely homogeneous medium. A range of work on variability has been undertaken before and after the 2011 ESC e.g. references [24,25,26,27,60]. We are addressing various aspects as part of our Technical Development Plan. We envisage that local-scale models, perhaps on the scale of a few ISO containers, would be used to investigate variability. The scale of and processes within each local-scale model would be selected taking account of model objectives. Such local models would be able to represent transport and chemical processes and would be used to investigate different sorts of variability, including:

- spatial variation in the distribution of the inventory including the bulk inventory, the contaminant inventory and the distribution of organic materials and complexants;
- the concentration of flows in the inter-container spaces or in cracks and transport to and from those cracks;
- effects associated with the distribution of grout;
- local variations in pH and Eh;
- the effects of progressive container failure;
- the influence of gas migration on the establishment and persistence of reducing conditions;
- variations in the degree of saturation.

A range of cases would be defined for investigation.

The Best Available Techniques (BAT) study being undertaken to consider containment (see Section 4) might suggest different approaches to the disposal of wastes in a vault. These potential changes could be investigated using these or other models and the models might require modification to represent potential design changes.

The programme of work would result in a better understanding of the effects of variability and associated processes. There could be various options as to how to address different aspects in the ESC including:

- the representation of specific additional processes in the assessment model;
- an upscaling approach leading to a treatment in the assessment model;
- address the effects in underpinning models, but leave the assessment model largely unchanged.

We will consider these alternatives, but we do not favour an unduly complex assessment model.

3.2.3 Engineering Performance Assessment

In the 2002 Post-closure Safety Case (PCSC), a specific EPA was undertaken, but, this was not the case in the 2011 ESC. We intend to undertake an EPA as part of the 2021 ESC and link it to our treatment of barrier safety functions, data elicitation and our treatment of cap settlement and waste voidage. We do not intend that this will be as complicated as that attempted for the 2002 PCSC.

We envisage that an EPA would involve:

- setting out conceptual models for the evolution and degradation of each barrier and in particular identifying the processes or events that might result in significant deterioration of barrier function;
- defining an approach to understanding the extent of degradation as a function of time, which might involve judgment and/or numerical modelling;
- investigating the consequences of such degradation, for example using a groundwater flow model or a systems assessment model;
- ensuring that any interactions or correlations (e.g. localised failure of containers below a defect in the repository cap) between the performance of different barriers are identified and a practical approach is identified to address these;
- ensuring that there is a link between the models identified above and elicited data for barrier performance.

The EPA would focus on the groundwater pathway. It would cover the PoA and the period thereafter. We will consider the extension of the EPA to also address the gas pathway.

3.2.4 Criticality

We presented a criticality assessment as part of the 2011 ESC. We expect to review and update this assessment, broadly following a similar approach to that previously used.

3.3 Geology and hydrogeology

We would broadly use the same approach to address geology and hydrogeology. Improvements to the geological model have been implemented since 2011 and a revised geological model, including various quality checks, has been produced, which will be used as the basis for the 3-D groundwater flow model. The approach to representing heterogeneity in B2 and B3 will be reassessed along with assessment of the effects of climate change. The hydrogeological model will be used to consider the impacts of the changes to engineering design and optimisation.

We will review our approach to representing climate change and sea-level change, drawing on the review identified in Subsection 3.4. This will include consideration of changes in Hydrologically Effective Rainfall and the response of the saline transition zone to sea-level rise.

As part of the 2021 ESC, we would produce a revised hydrogeological conceptual model. This would include updates on all significant aspects of the system including the work on the distribution of lithologies within B2 [61] and the significance of the groundwater mound [62]. The hydrogeochemistry of the system will be reviewed to ensure that understanding is consistent with and incorporated within the conceptual model.

3.4 Environmental setting

Understanding of the environmental setting includes an understanding of the changes in climate and landform that will affect the site over the period of assessment, and an understanding of local resource use and human habits to inform the stylised representation of the biosphere (see Subsection 5.5).

We have undertaken an extensive programme of work in the recent past that addresses climate evolution and the effect of landform changes, largely the impact of rising sea level and coastal erosion on the region around the LLWR. We will review and update our understanding based on the latest global and regional climate and sea-level change information.

Coastal conditions and their evolution are being monitored on an annual basis, plus additional beach surveys may be undertaken to observe the effect of specific events, e.g. the powerful coastal storm events of Winter 2013-2014. The increasingly long record of local coastal conditions will provide a firmer foundation or basis for understanding local processes and projections of future evolution.

We will undertake a review of climate change science and projections. This review will also take into account any developments since 2011. We will also keep abreast of any proposed changes in coastal management along the West Cumbrian coastline. Developments in coastline management and coastal evolution modelling more generally will be reviewed to support a view on whether revised quantitative modelling of coastal recession is required, e.g. based on the CRM and SCAPE models used in support of the 2011 ESC or employing a new model.

Based on monitoring data and the reviews of climate change science, coastal erosion science and coastal erosion modelling we develop an improved conceptual model and understanding of coastal erosion and repository erosion sequence. This will include the implications of the degradation state of the waste, structure and presence of large items.

3.5 Local resource use and human habits

Calculation of present-day impacts from the LLWR, as presented in the annual retrospective dose assessments, are based on current land use patterns and human habits. Cautious assumptions concerning habits are made, e.g. considering an individual at the site boundary, and ingestion of milk from cattle drinking water entirely from the water source with highest level of radionuclide concentrations.

For assessments in support of the ESC, we take a more generic approach such that the calculated doses and risk do not vary or depend on exact or detailed local human habits. Rather, we define exposed groups that make use of the potentially most contaminated areas for whatever use these areas might reasonably sustain, e.g. using any potable water supply for drinking and watering of crops, dwelling on the contaminated land if habitable, visiting or undertaking leisure or occupational activities on contaminated areas, and ingesting marine foodstuffs. These provide a cautious basis for estimation of dose and risk to potentially exposed local inhabitants over the longer term.

We avoid extreme habits, e.g. very high consumption rates and deliberate consumption of soil (pica), and exposure from deliberate events to persons who are aware of the hazard. We do, however, assess inadvertent exposures to concentrations of radionuclides or other contaminants, e.g. as occur due to human intrusion into the repository, and exposure to durable items or radioactive particles as may occur on the beach and foreshore following the erosion of the LLWR.

Information on present-day habits in West Cumbria and Northwest England has been reviewed in reference [63], based on habit surveys. Information has been generalised to derive habit data for potentially exposed groups (PEGs) using different environments in the vicinity of the LLWR in the future. We will:

- update the summary of habit survey making use of more recent habit data;
- review the PEGs that we use and their assigned location and behaviour, taking note that some individuals may be able to receive doses via more than one pathway;
- systematically review the data that characterise the behaviour of each PEG;
- consider whether any further surveys need to be undertaken or data acquired.

4 Options Assessment and Site Management Plan

4.1 Design optimisation

The NS-GRA sets as a principle, Principle 2, Optimisation: *'Both at the time of disposal and in the future, the radiological risks to people and the environment from a disposal of solid radioactive waste shall be as low as reasonably achievable under the circumstances prevailing at the time of disposal, taking into account economic and societal factors and the need to manage any non-radiological hazards*.' The NS-GRA comments that optimisation should be considered at all stages in the lifecycle of the disposal facility, including use of the site and facility design, construction, operation and eventual closure.

This is confirmed as 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 and to the environment, both during the period of authorisation and afterwards, are as low as reasonably achievable (ALARA), taking into account economic and societal factors*.'

As noted in the NS-GRA:

- optimisation is about finding the best way forward where many different considerations need to be balanced;
- the developer/operator should carry out options studies, where there are choices to be made between significantly different alternatives;
- the best way forward is not necessarily the one that offers the lowest radiological risk;
- once a decision has been implemented, it forms part of the framework within which further decisions must be made.

We consider that optimisation is achieved by implementation of sound, safety-informed choices concerning the facility design, wastes to be disposed and operational management of the facility. Such choices are made based on the scientific and technical understanding of the disposal system and its performance.

A number of optimisation studies have been undertaken prior to and after the 2011 ESC. These were undertaken using a BAT methodology. Thus much of the design and site management is underpinned by a BAT study. These studies (e.g. those related to repository design and potential waste retrievals) need to be reviewed to ensure that the assumptions underpinning them have not changed. However, the need for major new BAT studies is now less than it was at the time of the 2011 ESC. In the 2011 ESC we identified the containers as one area where work is required. We have recently completed a study looking at the current container design and are currently undertaking a BAT study for containment (see Subsection 4.2). The output will provide the basis for a revised design (if appropriate) and optimisation arguments in the 2021 ESC.

Since the 2011 ESC, further work has also been undertaken on optimising the hydrological management of the trenches and, in particular, of the interim trench cap [64].

The 2011 ESC was based on 'conceptual' future engineering designs. Before construction, further detailed design optimisation is required. This will be carried out in work under the Engineering Plan, which is reported separately. Between now and the next ESC, the ESC team will devote significant effort to supporting optimisation of key engineering components such as the cap and the leachate management system.

A specific enhancement is the creation of a RMS (see Subsection 4.3), which will ensure that there is a better link between the engineered design and the ESC and other requirements (e.g. those deriving from national policy). The system will ensure that optimisation decisions are recorded and that the design conforms to performance requirements.

Overall, in the 2021 ESC, we will make an integrated presentation of the arguments and evidence concerning design, system understanding and assessment, to show that we have done all that we reasonably can in terms of design and site management to ensure that present and future radiological impacts are as low as reasonably achievable.

The 2021 ESC documentation will describe progress that is expected to have been made in higher stacking in Vault 8, repairing the interim trench cap, and progressing final capping of Vault 8 and the northern end of the trenches.

4.2 New options studies

One aspect of optimisation not considered in the 2011 ESC or subsequently is container design, with the previous optimisation study being undertaken several years before the submission of the 2011 ESC. Therefore, we are undertaking a wider review of the way that LLW is emplaced in the LLWR vaults. This will be focused on the containers and/or emplacement strategies that might be employed.

The initial phase of work, which has already started, is to assess different options and select any that are worthy of further consideration. A subsequent phase of work will be undertaken to select and to undertake more detailed optimisation of the selected option or options. The scope of this work is bounded by the current LLWR vault concept. Vault design has already been considered as part of the 2011 ESC optimisation work and this area is therefore not included within the planned scope.

Our current site development base line means that waste containers may be exposed to the elements for up to approximately ten years before final capping (or protection of some kind) is installed. It is therefore necessary to consider whether a more durable container might improve performance. The disposal options considered are likely to include:

- current ISO container design, re-optimised as appropriate;
- new steel containers;
- drums;
- concrete containers;
- soft-sided packages;
- disposal cells (within the current vault concept);
- direct disposal of large items.

The work may provide revised designs for use in the 2021 ESC and will provide evidence to demonstrate that optimisation has been undertaken.

4.3 Requirements management system and engineering optimisation

We propose to develop a RMS for the engineered design (see reference [65]). This will place decisions within a structured framework that clearly defines all of the requirements on the disposal system and its components and shows how these are interlinked and affect each other. RMSs are commonly used by international radioactive waste disposal implementation organisations to:

- clearly define requirements and assumptions on the disposal system and its components;
- make linkages and interdependencies explicit;
- to record formally the justification for decisions in support of design substantiation.

The RMS would probably be developed using proprietary software 'Dynamic Object Orientated Requirements System' or 'DOORS™', which is used by several international organisations responsible for implementing geological disposal of radioactive waste and for complex engineering projects. Key benefits are that the safety functions of each barrier are systematically recorded and evidence is provided that the design provides the safety functions claimed in the ESC (see Figure 4.1).

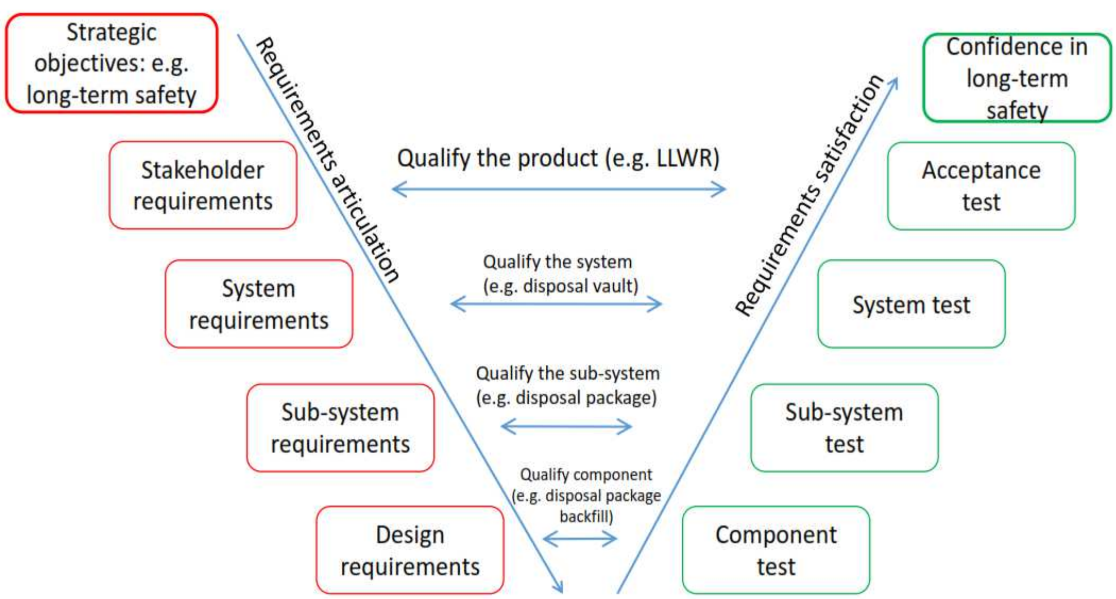

Figure 4.1 The 'V' diagram structure commonly used to demonstrate that structures, systems and components are delivering the safety functions claimed in the safety case

Overall, a RMS can be used to ensure that strategic and detailed design decisions account for safety case understanding and also the wider context of other stakeholder considerations such as operational safety, environmental impact, cost and schedule. It is a powerful tool to communicate safety arguments and increase confidence that engineered barrier system design decisions are based on a robust set of safety functions. The main output from this work will be a clear set of requirements for the repository design.

4.4 Institutional control strategy and information management

Once a repository is closed it will require some ‘institutional control’ for a period, to provide time for re-assurance monitoring of performance and to prevent intentional or inadvertent intrusion. Control might be ‘active’, that is, while the site is regulated and authorised by the Environment Agency. ‘Passive’ control might follow through measures such as local planning controls and maintenance of records in libraries and archives. Measures might also be taken before the end of active institutional control, such as the placement of markers, to discourage later intrusion.

A revised strategy for institutional control will be developed, which addresses aspects such as:

- long-term information management and retention;
- site-end state requirements;
- delicensing and withdrawal from regulatory control;
- monitoring;
- site access;
- site markers;
- implications of coastal erosion.

This would be a more detailed position than in the 2011 ESC where we investigated possible approaches, but did not present a detailed LLWR strategy.

A key requirement is to store relevant information over the duration of the PoA and make arrangement to ensure, or encourage, the retention of key information over the longer term. The retention and management of information will be reviewed in a task within the Technical Development Programme and will support arguments in the ESC. This review will cover information retention over a range of different timescales including steps that might be taken after the end of the PoA. It will take account of developing approaches to archiving of information owned by the NDA. We regard key information to include in particular information about the design of the facility and the characteristics of the wastes.

5 Assessment Approach

This section describes the approach to addressing NS-GRA Requirements R6, R7, R8, R10 and R11. The section describes the overall approach in each of the technical areas with special attention to areas in which we are planning developments of our approach and additional work for the 2021 ESC.

We will adopt an iterative approach in our assessments and have therefore made provision for two phases of assessment. After the first phase, we will review our models and results and decide whether any model enhancements or alternative calculations are required.

Peer review is an important element of the assessment approach. The process of peer review will continue over the period to the end of the 2021 ESC. This will include review of plans and approaches as well as draft assessment reports. We would aim to focus the peer review on key and novel elements of our approach. In particular, we expect to submit key ESC reports for review in draft form in order to enable implementation of any comments.

5.1 Data management

A rigorous approach to data management is necessary as part of the ESC.

We will implement a progressive data freeze at the start of the assessment calculations to underpin the 2021 ESC (we expect that this will start in early 2019) to ensure that consistent data are used across the assessments. The data freeze will be progressive to take account of the need to calculate some data from other input data and possibly to review and revise data values during the course of the assessment.

An updated and revised procedure will be used for data management in the 2021 ESC. As part of the revision, we will have considered extending the procedure to wider range of data types.

We will continue to use the data elicitation process employed as part of the 2011 ESC and will make progress in better documenting underlying arguments. Alternative elicitation protocols will be considered and a protocol selected that provides efficient and traceable elicitation and recording of both elicited data and assumptions and arguments that underpin the data.

For the 2011 ESC we have derived single parameter values and probability distribution functions as appropriate. These parameter values and distributions need to be reviewed to determine whether updates or revisions are required. If such are required, an appropriate process will be followed. We will consider and set out our process for review and revision of data prior to the 2021 ESC.

5.2 The Period of Authorisation

The 2021 ESC will include arguments and evidence for environmental safety over all phases of the facility development. In principle integration is desirable, showing for example that results of present day monitoring and the results of assessment models are consistent. We are developing an integrated PoA and post-PoA model for the groundwater pathway (see Subsection 5.6) in response to an Environment Agency request. For other pathways, e.g. the gas pathway, the nature of the exposed groups and the pathways themselves are different between the PoA and subsequently. For example, there is an exposed group that can be exposed to radiation from wastes before capping, but such exposures cannot occur after capping. Models for these other pathway therefore differ between the PoA and the period thereafter.

During the PoA, a key safety case argument is that the site is monitored and managed so that releases and impacts will be acceptably low. This will include the following considerations and arguments:

- Good practice is used to limit the releases from the facility by limiting the water inflows to the repository and collecting, and managing, the leachate arising.
- A suite of boreholes is regularly monitored for the release of chemotoxic and radioactive contaminants to the environment. Appropriate trigger levels have been defined. If these are exceeded, further investigation or action will be taken to ensure that the site is managed in an appropriate way. The generation of gas is also monitored and arrangements are in place during the operational period to ensure that this gas is vented to atmosphere. An Annual monitoring report is produced and this is provided to the Environment Agency. Similarly, anomalous results are considered, notified to the Environment Agency as required and any further actions or implications to the ESC are considered.
- Capping will proceed as vaults are filled and closed. As well as the primary function of limiting infiltration to the waste (and hence leachate for disposal) capping removes potential for scattered radiation exposure and is expected to reduce the release of radon from the covered vaults and trenches.

As noted above, an integrated assessment model for the groundwater pathway will be developed to provide continuous representation of the period from 1959 until expected erosion. In the 2011 ESC, we derived models that were very cautious with the objective of demonstrating that impacts are always less than the dose constraint set in the GRA for the PoA. We will review the models used and, where supportable, use more realistic models. This is with the aim of not only showing compliance with the dose constraint but also estimating the evolution of dose impacts from each pathway over the operating lifetime and after completion of disposals. This will provide a better understanding of the actual magnitude of radiological impacts to inform optimisation and also allow us to demonstrate that the annual dose impacts from the facility while under regulatory control fall below 20 μSv, i.e. they are consistent with the annual risk guidance value of 10^{-6} that applies after release from regulatory control.

5.3 Treatment of uncertainty

For the 2021 ESC assessments, we will retain the same approach of using alternative methods of exploring uncertainty approaches, flexibly and in proportion to the importance of the uncertainty and the data that are available. We will, however, make specific improvements where these assist in gaining fuller understanding of key uncertainties. Our treatment will also be more systematic and based on an approach set out in the Assessment Manual. It is noted that our treatment of uncertainty will vary between pathways. For example, we envisage carrying out probabilistic calculations for the groundwater pathway, but not for coastal erosion or human intrusion. We will consider the implications of uncertainties and assumptions in the biosphere, but we do not intend to treat human habits probabilistically.

As in the 2011 ESC, we will adopt a classification of uncertainties that is conventional in radioactive waste disposal assessment focusing on their mode of treatment in the safety assessment, thus:

- scenario uncertainty – are the (safety assessment) scenarios considered sufficiently complete in their representation of the possible evolutions of the disposal facility and its environment?
- model uncertainty – do the models describe the real world features and processes in an adequate way (in safety assessments we aim at not underestimating the impact)?
- parameter uncertainty – what impact do possible variations of the parameters have on the final results of the safety assessments.

An initial discussion is provided below of the treatment of each of these types of uncertainty (Subsections 5.3.1 to 5.3.2).

As noted in Subsection 2.7.1, an Assessment Manual will be written within the Technical Development Programme. This will set out an overall approach to the management and the treatment of uncertainties and biases. The approach will be more formal compared with the previous ESC in that the steps of identifying and characterising uncertainties will be explicitly recorded. The approach will provide a systematic analysis of uncertainties and explain how they are treated in the assessment.

5.3.1 Scenarios

We will follow a similar approach to that pursued in the 2011 ESC. Scenarios will be identified through expert judgement on the basis of detailed understanding of the wastes, repository, environmental setting and their evolution. The selection and definition of scenarios for quantitative analysis will be made by assessment modellers in collaboration with, and informed by, scientific subject experts. We will also include scenarios or cases as requested by the Environment Agency during their review of the 2011 ESC. We will also document key biases for each scenario and present them more systematically.

In broad terms, we will assess scenarios that consider the expected natural evolution of the LLWR and also scenarios that consider alternative and less likely scenarios. The assessment of expected natural evolution will take account of uncertainties related to the degradation of the wastes and engineered barriers and also changes in the local surface environment due to natural processes and human activities not directly compromising the engineered barriers or integrity of the closed repository. It may be convenient to assess some other uncertainties by developing alternative scenarios.

In the 2011 ESC, the expected natural evolution scenario, based on the available evidence, was that the repository will be disrupted and eroded due to coastal recession, with erosion of the repository commencing a few hundred to a few thousands of years in the future. This understanding may be refined during our review of climate change implications and local coastal processes (see Subsection 3.4), but we envisage that erosion due to coastal recession will continue to be an important scenario.

The assessment of the potential for, and impacts of, disruption of the site by natural processes will be founded on scientific descriptions of the disrupting processes and their progress. The assessment of the potential for, and impacts of, disruption of the site by unplanned human activities (i.e. human intrusion) will use information-based descriptions of most likely and reasonable human activities at the site, but ultimately the cases selected for analysis are necessarily stylised representations that illustrate possible events. As well as assessing the immediate impacts of disruptive events, we assess the longer-term effects of natural or human disruption events on the containment performance of the damaged repository.

5.3.2 Model uncertainty

Model uncertainty can apply to the conceptual model, which describes the phenomena and interactions included within an assessment case, the mathematical model, which is the representation of the conceptual model in terms of parameter values, mathematical equations and boundary conditions, and the computer model, which consists of the code used to solve the mathematical model. Of these, uncertainty in the conceptual model is usually most important. The conceptual model uncertainty may relate to lack of knowledge of the processes but also, often most significantly, to deliberate simplifications in terms of spatial resolution and averaging or omission of processes. The aim is to create a model that is cautious in its representation and does not underestimate consequences, e.g. omitting a process that is thought to be beneficial to safety but for which insufficient data are available.

We will consider in each case whether there are alternative models that are plausible. If such models exist, we may choose to adopt a cautious approach to identify and discuss any bias that might arise from the omission of some process or in some cases to explore an alternative model.

5.3.3 Parameter uncertainty

As in the 2011 ESC, we will continue to present a combination of deterministic and probabilistic calculations. This “mixed” approach can be seen in recent performance assessments that are widely regarded as 'state-of-the-art' from countries such as Sweden and Switzerland. We value probabilistic calculations as a method of exploring uncertainties within quantitatively defined models, but note that this misses what may be very important uncertainties, due to limitations in the conceptual model (e.g. incomplete understanding or omissions) or limitations in the mathematical or computer model (e.g. inability to handle variations in time).

For the 2021 ESC, we propose to carry out deterministic calculations using reference parameter values and to explore model sensitivity using a combination of deterministic (point value) calculations and also probabilistic calculations over credible parameter ranges where this is appropriate for the most important scenarios. Results of sensitivity analysis will be used to identify key parameters in the most important scenarios. Only then will attention be given as to whether justified probability distributions can be developed for parameters that are most important to performance.

We will adopt a more formal approach to identifying the key uncertain parameters, undertaking variant calculations to assess impacts and presenting information about the uncertainties. This approach will be set out in the Assessment Manual (see Subsection 2.7.1).

We envisage that probabilistic calculations will be undertaken for the groundwater well pathway. We will consider the merits of probabilistic and deterministic calculations for the C-14 gas pathway (e.g. related to uncertainty in evolution of vault chemical conditions and release of C-14 bearing gas) and for the coastal erosion pathway (e.g. related to uncertainty in longevity of eroded wastes on the beach including more durable items).

5.3.4 Register of uncertainties

A sufficient set of calculations will be carried out to provide confidence that the assessment has adequately explored uncertainties related to scenarios, models and parameter values, and to combinations of these uncertainties. In addition, a register of significant uncertainties will be established and maintained, which indicates how these have been addressed and the extent to which further data gathering, calculations or decisions are needed. It is intended that this will be an evolution of the FEP and Uncertainty Tracker developed for the 2011 ESC [20]. However, the tracker will be modified to focus on the key uncertainties, and uncertainties that require further management (see Subsection 2.7.1) rather than providing a record as to how all FEPs are treated in the assessment. A key requirement of our presentation will be to demonstrate how each key uncertainty is represented and managed.

We also propose to audit the conceptual and numerical models used in our assessment against standard FEP lists to identify any key out-of-model processes. This activity will be closely linked to the bias audit discussed in the next subsection.

5.3.5 Bias audit

A bias may be an assumption, condition, or caution within models (or any other aspect of a process in a model) that results in, or is likely to result in, an inaccurate representation of the system under consideration. We envisage that part of our approach will be to undertake a bias audit across the different assessment calculations. The aim of the audit would be to provide information on out-of-model processes and to assess the impact of each bias. In some cases, as appropriate, it would be argued that not treating a particular aspect is cautious or not significant. Where this is not the case, we would seek to provide quantitative information on the impact of not modelling the bias. There will clearly be a significant link between identified biases and our list of key uncertainties.

5.4 Variability

Properties of various media within the repository system will vary from place to place. Such spatial variability can influence the performance of the system. For example, as demonstrated in calculations undertaken in support of the 2011 ESC, the plume of contaminants in groundwater may be localised rather than evenly distributed between the facility and the coast (see for example Figure 5.13 of reference [66]) because of the heterogeneity in the hydrogeological properties of the geosphere.

We will set out an approach to the recognition and treatment of spatial variability in the Assessment Manual (see Section 2). Our overall approach will be:

- to identify key sources of variability in the system;
- to undertake a detailed evaluation of prioritised types of variability in the near field (see Section 3);

- to undertake a set of supporting calculations for the groundwater pathway to explore implications for the groundwater pathway.

A key focus will be on the groundwater pathway, for which we will consider the effects of spatial variability in the near field (see Subsection 3.2.2) and geosphere. Attention will also be given to discrete items and high activity particles that will become exposed or encountered as a result of coastal erosion or human intrusion. Our approach to modelling the C-14 bearing gas pathway assumes that chemical interactions are localised.

5.5 Treatment of the biosphere

There are large uncertainties about the evolution of the surface environment (the biosphere), and the habits of humans living in the future. For this reason, the ICRP cautions that estimates of doses and risks should not be regarded as measures of health detriment beyond times of around several hundreds of years (ICRP, 1997), but rather that that estimates of doses and risks should be compared with appropriate criteria in a test to give an indication of whether the repository is acceptable (ICRP, 2000). That is, the calculations are made for the purposes of converting radionuclide releases to the biosphere to a scale relevant to radiological safety, i.e. dose and risk, so that they can be compared with a regulatory or other performance target. They are not to be interpreted as actual doses to humans dwelling in the future.

Another factor is that whereas the properties of the engineered barriers can be optimised by design, and are relatively stable or predictable, the properties of the biosphere in the future are dynamic and outside our control. Thus, whereas assessment of the engineered barriers can be used to guide and design, and to improve potential performance, assessment of the biosphere can only tell us about the putative impacts of radionuclides once in the biosphere. Biosphere assessment is important in that it provides the basis to make the calculations needed to judge whether safety criteria expressed in terms of dose or radiological risk are met, but generally it does not tell us how to design a better repository.

In order to develop assessment models to estimate annual dose to humans, it is most appropriate to focus the development of the biosphere model on the present day exposed groups and future PEGs. In the future, these are hypothetical population groups that might occupy or draw resources the various tracts of land or water that are liable to become contaminated as a result of radioactive waste disposal at the LLWR.

As discussed in Subsection 3.5, we will review the PEGs that we use and their assigned locations and behaviours, and review the data that characterise the behaviour of each PEG.

5.6 Groundwater-mediated pathways

Our general approach for modelling the groundwater pathway is to use the GoldSim software [67] to create system assessment models similar to those used in the 2011 ESC. We will pursue a treatment of the well pathway as in the 2011 ESC and documented in reference [68].

The following enhancements are planned:

- calculations will be undertaken on the basis of an updated geological and hydrogeological model, largely based on existing data;
- an assessment model will be developed covering the PoA and the period thereafter with a representation of progressive trench and vault construction and inventory disposal;
- as described in Subsection 5.3, a more formal and rigorous treatment of uncertainty will be offered;
- supporting calculations will be presented to show that there is an understanding of different sorts of spatial variability in the near field and geosphere;
- calculations will be used to support an analysis of the future performance of barriers;
- the near-field model will be enhanced if considered appropriate on the basis of the near-field development programme;
- input data will be systematically reviewed;
- there will be a link with the EPA (see Subsection 3.2.3);
- a revised model will be developed to represent discharges to the near-surface environment in the vicinity of the repository, i.e. the Stream pathway model will be revised.

5.7 Gas-mediated pathways

We will pursue the treatment of C-14 developed subsequent to the 2011 ESC and used in support of the Permit application [13]. Data inputs will be reviewed to take advantage of any new information, in particular, related to C-14 bearing waste form and release of contaminants as studied in the NDA Carbon-14 Integrated Project Team [69]. The revised assessment model provides a representation of the largely unsaturated, containerised, heterogeneous conditions in the vaults after completion of closure engineering (capping) over each vault. Account is taken of the different waste forms in which C-14 is disposed. A less cautious model of the biosphere was used in that more realistic mixing of C-14 bearing gas within the plant canopy atmosphere is represented.

Radon occurs naturally and makes the largest contribution to the estimated average dose due to natural sources in the UK. This exposure is due to radon daughters attached to dust in indoor air. In the 2011 ESC, a detailed study of radon and radium in soil, and radon in associated dwellings in the UK, was undertaken by the Health Protection Agency (HPA) (now Public Health England - PHE) and the British Geological Survey. This was used to underpin a simple empirical model that provides estimates of radon in buildings constructed on the repository cap or waste excavated from the repository. This is a robustly underpinned approach, which we will continue to use in the 2021 ESC.

5.8 Coastal erosion

The assessment model for assessment of the radiological impacts from erosion of the repository used in support of the 2011 ESC possessed several key features. These included representation of the repository using an orthogonal grid of 44 cells across which an erosion front traversed resulting in the release of wastes and radionuclides through a cliff front onto a beach and foreshore of constant volume. This allowed the representation of large-scale heterogeneity of distribution of radionuclides within the repository and resulted in changes in the radionuclide inventory of the cliff, beach and foreshore areas as different wastes were eroded. A further key assumption was that individuals using the cliff, beach and foreshore areas for leisure or occupational purposes would traverse the areas randomly spending time on each area proportional to their time-averaged accessible area. This means that the exposure of a shore user is proportional to the average concentrations of radionuclides in the cliff, beach and foreshore areas weighted by time spent in each area.

During their review of the 2011 ESC, the Environment Agency raised several issues around the potential for exposure to materials of above average activity and especially exposure to high-activity particles - this by analogy with concerns over high-activity particles found on beaches near to Sellafield and Dounreay, and at Dalgety Bay. We carried out extensive calculations to assess the potential for exposure to high-activity particles and small items, and were able to show that the impacts were consistent with both the risk guidance values in the GRA and new guidance provided by the Environment Agency for limitation of radioactive items [70].

Since 2011 we have developed WAC to control heterogeneity of waste at these scales by limiting the presence of what we now define as ‘Discrete Items’ and ‘Active Particles’. We believe the WAC will adequately control heterogeneity such that the calculation of risk to shore users based on an average concentration throughout the wastes at the cliff, beach and foreshore is valid. This has been demonstrated for the case of Active Particles in our responses to the Environment Agency’s review comments on the 2011 ESC. We have not, however, formally shown this to be so for the case of large numbers of Discrete Items deposited on the beach and foreshore.

In support of the 2021 ESC we will review the 2011 coastal erosion assessment model, paying attention to uncertainties in the erosion and radionuclide loss processes, for example to:

- the vertical dimension of the vaults, trenches, profiling and cap materials and account for changes of sea level during the erosion of the repository;
- alternative forms of erosion front, including slumping of an eroded cliff front, direct erosion and partial inundation;
- heterogeneity and effect of presence of Discrete Items, including estimates of beach longevity of items and contamination thereon;
- the resistive effect of wastes and engineered elements to erosion including build up of durable large Discrete Items on the beach;
- the loss of radionuclides from the beach and foreshore by leaching or wash off of fine particulate material, e.g. corrosion products.
- the behaviour of exposed persons on the cliff, beach and foreshore.

Scoping calculations will be used to gauge which features and processes not currently included in the model should be included.

5.9 Human intrusion

We believe the approach to, and model for, human intrusion used in support of the 2011 ESC is well-matched to the requirements of the NS-GRA. Therefore, for the 2021 ESC, we will undertake a review of input data, but otherwise the approach will be very similar to that presented as part of the 2011 ESC.

During their review of the 2011 ESC the Environment Agency raised several issues around the potential for exposure to materials of above average activity and exposure to high-activity particles, similar to those raised for the assessment of coastal erosion. We will use results from our work to address the Environment

Agency issues to augment our presentation of human intrusion in the 2021 ESC. In response to ESC-FI-003, we will present a fuller 'what-if' assessment of a deep-seated fire occurring during the construction or operation of a borehole drilled into trench waste.

5.10 Non-radiological assessment

A number of developments have occurred as a result of work completed since the 2011 ESC (e.g. [14,71]). These will be incorporated in the ESC presentation. Our existing approach takes full cognisance of the requirements of the Groundwater Daughter Directive, noting the Environment Agency supplementary guidance on this matter [30]. The main changes since the 2011 ESC are:

- adopting the same compliance points as for a landfill;
- addressing those substances whose status has changed or may change from non-hazardous pollutant to hazardous substance;
- incorporating a wider range of substances in the assessment as a result of a review of the inventory [71];
- using a single model to represent the evolution of the repository from 1959 into the post-closure period (see Subsection 5.6);
- revising the solubility of lead in accord with a recent detailed study [72];
- undertaking calculations based on declared inventory where this is available;
- undertaking impact calculations on the basis of observed concentrations in leachate, noting that for some substances no inventory is currently available.

Improving the inventory is a key underpinning task. We have been working with Radioactive Waste Management and the NDA to develop an improved treatment of non-radiological contaminants in future national inventories. We will also work to derive inventories of disposed substances (for which inventory estimates are not yet available) on the basis of newly-derived fingerprints where this is practicable. We consider that an ongoing process of inventory improvement is required linked to discussions with consignors.

Since 2011, we have carried out a detailed assessment of the potential risk from asbestos-bearing waste disposal at the LLWR [73]. In the 2021 ESC, we will present calculations of risk taking account of updated inventory information, which is being compiled by the National Waste Programme.

5.11 Non-human biota

Radiological impacts to non-human species that could arise from waste disposal at the LLWR are recognised as especially important because of the location of the site, which is bordered to the south and west by important natural environments encompassed by the Drigg Coast Site of Special Scientific Interest and Special Area of Conservation.

In the 2011 ESC, we assessed radiation doses to non-human biota using the ERICA methodology and propose to use this approach again in the 2021 ESC taking account of developments in the ERICA methodology and data. During their review, the Environment Agency identified some aspects needing fuller attention and some aspects need to be reviewed to determine whether any enhancements are required. Aspects requiring attention or review are:

- full compilation of radionuclide concentrations in the soils, sediments and water bodies and sources that non-human species may inhabit or depend on, i.e. the input data for ERICA assessments;
- the latest advice from the ICRP, which we understand may be issued in the near future;
- developments in the ERICA methodology or program;
- other research on approaches to estimating radiological impacts to biota;
- the choice of representative species for assessment and matching them to the species observed at the site and locally;
- discussion of and use of monitoring data.

6 Waste Acceptance

A comprehensive approach to waste acceptance and capacity management, linked to the performance assessments, was developed as part of the 2011 ESC and will be followed again. This approach ensures that the WAC and our approach to capacity management reflect the assumptions of the ESC to ensure that only waste that is consistent with the ESC is accepted for disposal. Our approach covers both radiological and non-radiological contaminants with appropriate limitations on both.

In the 2021 ESC, we will explain the link between the ESC and the WAC and if necessary revise the WAC to be consistent with our calculations and cases. We also intend to calculate radiological capacities relating to the groundwater pathway using a probabilistic assessment. Capacity and specific activity constraints related to other pathways will also be reviewed and recalculated.

The following changes are or will be key developments that will be reflected in the 2021 ESC.

6.1 Asbestos

Since the 2011 ESC, we have undertaken further work on the implications of disposed asbestos becoming exposed on the beach as a result of coastal erosion. This study included an assessment of options available for conditioning of asbestos in order to provide us with the necessary information to revise the WAC for asbestos.

In March 2016 we published a revised version of the WAC for consultation with customers. This version of the WAC contains more detailed criteria for the acceptability of asbestos for disposal to the repository based on the amount, type and form of the asbestos.

As part of our presentation on optimisation, we will set out arguments relevant to asbestos that is already disposed.

6.2 Carbon-14

As discussed in the forward programme section of the 2011 ESC, we undertook a review of our biosphere model of the impact of C-14 and also the release mechanisms of C-14 from different wasteforms. A revised conceptual model for C-14 bearing gas release was developed, as was a revised biosphere model. This new information was used to develop a revised assessment model from which a radiological capacity for C-14 for the vaults was calculated. It is expected that the C-14 assessment model will be reviewed as part of the 2021 ESC (however, major revisions to the model are not anticipated) and this review, combined with the consideration of future UKRWIs may lead to a revised C-14 capacity.

6.3 Discrete items and active particles

As part of their review of the 2011 ESC, the Environment Agency raised four regulatory issues about the presence of high-activity particles or items in the LLWR, in particular, the potential for high doses due to encounter with such particles (if present) during coastal erosion or human intrusion. Alongside this, we had noted in the 2011 ESC that we had not yet assessed the potential for exposure to larger durable items of waste that might be deposited on the beach during coastal erosion.

We responded to the regulatory issues, and our responses were reviewed by the HPA on behalf of the Agency, as part of the 2011 ESC review process. Resulting from this, the Agency developed supplementary guidance for assessing radioactive items and particles and we carried out further work to show that the assessed effective doses for any such small items or particles in the LLWR were consistent with the Agency's guidance.

Subsequently, we carried out assessments to underpin the development of WAC for what we now term Discrete Items [74] and Active Particles [75]. As part of ongoing dialogue with consignors, we have proposed to amend details of the limit that applies to Discrete Items. This change is included in the version of the WAC that went out for consignor consultation in March 2016.

We are not anticipating any fundamental changes to the WAC for either Active Particles or Discrete Items, but we are discussing the application of the WAC with consignors and will review the WAC to check that if offers the required level of protection.

6.4 Organic complexants

The previous environmental Permit prohibited the acceptance of chemical complexing and chelating agents. Our position as set out in the 2011 ESC was, subject to a revised Permit that so allowed, that we could accept complexing agents in certain quantities. Subsequent to the 2011 ESC work was carried out to review common decontamination agents and assess the impact of the complexants they contain. The outcome of this work was the identification of two categories of complexants for inclusion in the revised WAC. Category one materials are not controlled, but can only be disposed in quantities less than 1 kg, and Category two materials require control via a site capacity.

Work is currently ongoing with customers to develop a methodology for quantifying the amount of complexants in waste requiring disposal at the repository. We anticipate that review and further refinement of our approach is likely before the 2021 ESC.

We note that a key element of our approach is to continue to monitor the concentrations of relevant organic complexants in trench leachate.

6.5 Non-radiological contaminants

In the 2011 ESC we described our proposed approach to the management of non-radiological contaminants. We intended to use an approach similar to that for the radiological elements in the utilisation of a repository capacity for certain materials and recording the presence of others. Since the 2011 ESC, further work has been undertaken to refine this approach and review the list of contaminants that we intend to control. The main change has been the inclusion of control of waste with a complex material composition, notably steels and WEEE (Waste Electronic and Electrical Equipment) into the list of materials that require a capacity. There have also been significant developments in our methodology for leach testing of wastes to support waste acceptance. We anticipate that review and further refinement of our approach is likely before the 2021 ESC.

6.6 Voidage

One of the main long-term barriers at the Repository is the final engineered cap that is to be constructed over the Repository. As part of the 2011 ESC, a significant amount of work was done on the resilience of the cap in particular in relation to damage due to differential settlement. One of the aspects that can affect this settlement is the amount of voidage (or potential voidage) in the waste packages. In the 2011 ESC we proposed to restrict the amount of total potential voidage allowed in a waste consignment.

As part of the revision to the WAC made in 2013 we introduced a 20% limit (unless an agreed variation is in place) on the total potential voidage permitted in a consignment. Further work on design justification may lead to changes in our detailed approach to voidage.

6.7 Updated capacities

Some of the work described above, such as on C-14 and organic complexants has led to the revision of some of the capacities detailed in the 2011 ESC. For example, the acceptance of complexing agents has an effect on the site capacity for some contaminants. The updated capacities were recorded in the Technical Development Report [14], submitted as part of the permit application.

If future development activities result in a change to assumptions or modelling approach or there is a change in regulations then the implications for repository capacity and WAC will be considered. Any new information will be assessed under the ‘assessment of new information’ process. If such changes necessitate a change to the WAC then these changes will be discussed with the regulator. Such changes might also require a review of wastes that have already been disposed.

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7 Summary

In the following pages, we have provided a summary of the key developments that we expect to incorporate in the 2021 ESC (see Table 7.1). In Table 7.2, references are provided to Environment Agency FIs to show how these will be addressed.

Table 7.1 Key Developments in the 2021 ESC

New Aspect of the 2021 ESC	Description	Subsection Reference
Approach to ESC		
'Independent safety' arguments	Draw on review of independent and alternative safety arguments	2.6
FEP and Uncertainty Tracker	Change objectives of the FEP and uncertainty database. Currently, mainly a list of FEPs treated in the assessment calculations. Replace by database of uncertainties and biases used to demonstrate consideration, prioritisation and resolution of those uncertainties and biases.	5.3.4
Documentation	Adopt a similar document structure to the 2011 ESC. Envisage additional Level 2 reports on Uncertainty and Safety Functions.	2.7.1
Presentation and Stakeholder Communication model	Use tool(s) for stakeholder communication, coupling illustration of repository development (waste emplacement and engineering) plus possibly post-operational site development, site evolution, occurrence of impacts. Produce at least part of the ESC as a web document hyperlinked to reference material and to the stakeholder communication tool.	2.7.2

New Aspect of the 2021 ESC	Description	Subsection Reference
Underpinning Work and Models		
Updated and revised conceptual models	We will develop revised conceptual model reports for: Geology and Hydrogeology (including a discussion of hydrogeochemistry) Near Field Coastal Erosion Engineered Barriers and use these as a basis for our models and treatment.	2.7.1
Hydrogeology	Use a similar calibrated model to that used in 2011. A new 3-D model will be developed taking account of work in the Technical Development Programme (e.g. more refined representation of B2) and including a detailed representation of the repository.	3.3
Near Field	For the groundwater pathway, we have identified a number of aspects of variability and near-field processes that will be investigated in the Technical Development Programme. We intend to present a fuller treatment and understanding of variability. Some of this understanding may lead to changes in the assessment model.	3.2.2

New Aspect of the 2021 ESC	Description	Subsection Reference
Near Field Chemical Calculations	We will use an appropriate software tools to model the geochemical evolution of the near field and support our assessment models. This will include consideration of pH and Eh evolution and bulk gas generation.	3.2.1
Assessment Approach		
Overall Approach to Modelling	We will develop a more integrated approach to modelling involving team working and where appropriate sharing of model components.	5
Assessment Manual	An Assessment Manual will have been produced as part of the Technical Development Programme. Use as a more formal basis for approach in the 2021 ESC.	2.7.1
Safety Function Approach	Adopt a safety function approach in which we present our understanding of the function of each barrier, based on calculations and examine realistic failure of each barrier.	2.2
Analysis of Uncertainty and Bias	Present a systematic analysis of uncertainty and bias in the assessment.	5.3
Scenarios	Review and audit scenarios against review comments, FEP and process lists. Similar approach to that in the 2011 ESC.	5.3.1

Data Review	Review data and parameter distributions and revise using a logical and formal approach, which will have been set out in the Assessment Manual.	5.1
Assessment		
Enhanced Inventory	Use an improved inventory of non-radiological contaminants by using fingerprint information for current wastes. Make use of improved ability to derive location of wastes taking account of alternative assumptions on arising and on waste treatments and packaging (and any emplacement strategy rules). Provide single source of common data to all assessment models.	3.1
Treatment of Inventory Uncertainty	Reconsidered and improved treatment of inventory uncertainty.	3.1
Review and document approach to PEGs	Draw on a review of PEGs and the parameters that characterise their behaviour.	3.5, 5.5

New Aspect of the 2021 ESC	Description	Subsection Reference
Assessment of the groundwater pathway	Adopt broadly similar approach to that in the 2011 ESC, but with the possibility of certain enhancements to the treatment of the near field. More systematic treatment of uncertainty Supporting analysis of the impact of spatial variability Development of a model of the groundwater pathway with an integrated approach to model the PoA and the period thereafter. Possible enhancements to the representation of the near field that are not yet decided.	5.6
Assessment of the gas pathway: C-14	Adopt the approach followed in the work undertaken to support the Permit Application but check for new data.	5.7
Assessment of the gas pathway: Radon	No change in basic soil gas concentration-to-exposure model. Analysis of two-year radon monitoring data - potential for better understanding of release from trenches.	5.7

New Aspect of the 2021 ESC	Description	Subsection Reference
Assessment of coastal erosion	Examine international work on climate and sea-level change and review developments in coastal understanding and modelling. Thence, update the descriptions of possible erosion sequences and decide whether further use of underpinning numerical models is warranted. Undertake a review of the assessment conceptual model for coastal erosion and its implementation in the numerical model. Make developments as needed to focus on capturing key uncertainties (including heterogeneity and distribution of key radionuclides within the waste and waste items) either within the model or through model cases. Assess a range of cases to investigate the impact of uncertainties in the erosion sequence, heterogeneities of the wastes and behaviour of PEGs. Either treat heterogeneity explicitly, or demonstrate that the averaging assumptions applied are appropriate.	5.8
Assessment of human intrusion	No change, other than relating to choice of parameters, except that the treatment of heterogeneity at item and particle scales that was developed after the 2011 ESC will be incorporated.	5.9
New Assessment of Impacts during the PoA	Current calculations based on cautious assumptions – need to develop more realistic models. (See groundwater pathway above.)	5.2
Engineering Performance Assessment and Settlement	Undertake a simple EPA.	3.2.3

	Linked to developments in treatment of cap resilience and data elicitation.	
Assessment of Non-radiological Impacts	Adopt a similar approach to that pursued in calculations for the Permit Application. Enhanced approach to inventory (see above) and consideration of a wider range of contaminants. Link assessment to monitoring data.	5.10
Organic complexants	Pursue current approach. Important link to monitoring data.	2.4 & 6.4
Non-human biota	Similar approach to the 2011 ESC. Update data and consider ICRP and other developments.	5.11
Waste Acceptance		
Waste Acceptance	Use probabilistic calculation as a basis for WAC for the groundwater pathway.	6
ESC Management		
Information Management and Retention	Improved arguments from Technical Development Programme activity.	4.4
Institutional Control and Site End State	Improved arguments from Technical Development Programme activity.	4.4

Optimisation and Engineering		
Requirements Management System	Develop a RMS for the Repository Design - will record safety functions and reasons for design decisions and specifications and link them to assessment and ESC requirements.	4.3
Containment Options Study	Complete currently ongoing options study into the way that wastes are disposed in the vaults.	4.2
Engineering arguments	The 2021 ESC will draw heavily on arguments developed in work under the Engineering Plan, for example in relation to vault and cap design and leachate management.	4 and Engineering Plan
Monitoring		
Monitoring	Draw on monitoring arguments, including LLWR strategy for long-term monitoring, organic complexants and colloids.	2.4

Table 7.2 Treatment of Forward Issues

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
ESC-FI-001	Cap settlement issues	LLW Repository Ltd should develop and implement a work programme to identify an optimised cap design and container stack heights.	An optimised cap design will be developed before the 2021 ESC. Higher stacking in Vault 8 is addressed in a report that is currently being prepared.	See Engineering Plan.
ESC-FI-002	Tritium monitoring and establishment of trigger and action levels	LLW Repository Ltd should continue to monitor tritium throughout the period of authorisation in line with our requirements outlined in this FI.	It is planned to continue tritium monitoring and to use the data as effectively as possible.	2.4/ See Activities 91, 92, 93, 94 and 95. The ongoing monitoring programme will also address.
ESC-FI-003	Revised borehole fire assessment	LLW Repository Ltd should present a 'what if' type assessment of a deep seated fire occurring during the construction or operation of a borehole drilled into trench waste.	A fuller assessment will be undertaken.	5.9/ See Activity 248.
ESC-FI-004	Forward programme	LLW Repository Ltd should further develop and update its forward programme of work to make sure there is continued improvement of the ESC.	This requirement is fulfilled by the Technical Development Programme.	See Technical Development Programme. The ESC work programme will be reviewed and updated at least annually but will constantly evolve.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
ESC-FI-005	Use of monitoring to reduce uncertainties in the ESC	LLW Repository Ltd to collate and integrate monitoring objectives, strategies and procedures in a single document, so as to provide evidence of how the forward monitoring programme will be implemented and developed throughout the period of authorisation and linked to the ESC to reduce uncertainties.	The overall objective would be addressed by inclusion of material in the Monitoring Level 2 document that we would produce as part of the 2021 ESC.	2.4/ See Activities 73, 74, 75, 76, 77, 78, 91, 92, 93, 94, 95 and 97.
ESC-FI-006	Non-radioactive groundwater assessment reporting	LLW Repository Ltd should update the hydrogeological risk assessment for the LLWR for issue by December 2017.	We are developing a plan, which we shall be submitting to the Environment Agency.	-/ See Activities 218, 219, 220 and 221.
ESC-FI-007	Inaccessible voidage minimisation procedures and emplacement strategies	LLW Repository Ltd should have appropriate procedures in place to make sure that potential container settlement remains within acceptable limits and that placement is optimised.	This activity falls within the scope of the Engineering Plan	See Engineering Plan/ There is also a link to Activity 29.
ESC-FI-008	Management of uncertainty	LLW Repository Ltd should further develop the FEPs and uncertainty tracking system (or alternate tools) as a tool to manage uncertainty in the ESC and feed into the forward programme.	We are proposing to modify the Tracker to focus on recording and managing uncertainties and biases.	5.3.4/ See Activities 7 and 8.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
ESC-FI-009	EDTA analysis to support the complexant assessment	LLW Repository Ltd should undertake further work to underpin the conclusions of their assessment of complexants such as EDTA. Further work is required to continue to improve LLW Repository Ltd's knowledge of complexants leaching from the trenches and the vaults and the risk this may have via the groundwater pathway.	We plan to continue monitoring and enhance our waste acceptance approach	2.4 and 6.4/ See Activities 69, 70, 91, 92, 93, 94 and 95.
ESC-FI-010	Waste heterogeneity in Vault 8 and future vaults	LLW Repository Ltd should undertake further work to understand the distribution of key radionuclides and key materials in Vault 8 and future vaults. This work will allow LLW Repository Ltd to demonstrate via the ESC their understanding of the distribution of these species and materials in the vaults.	There is currently an understanding of the distribution of wastes and radionuclides in Vault 8 in that these data are recorded in the Low-Level Waste Tracking System. This information will become available for future wastes as disposals occur. The data have been used as a basis for a recent study on the disposal of stored wastes. We will continue to use understanding of the distribution of radionuclides and materials within work to	-/ See Activities 32 and 54.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
			understand variability and voidage.	
ESC-FI-011	Forward review of the extended disposal area	LLW Repository Ltd should fully integrate the EDA assessment into the ESC at the next periodic review of the ESC.	There will be no need to undertake a separate assessment of an EDA repository as part of the 2021 ESC – our presentation will comply with the Environment Agency's request under this FI.	-/ See Activities 4 and 5.
ESC-FI-012	Use of probabilistic calculations in derivation of radiological capacity	LLW Repository Ltd should consider update of the probabilistic groundwater pathway	We will use probabilistic calculations for the groundwater pathway to derive capacities.	6/ See Activities 115 and 116.
ESC-FI-013	Assessment of discrete items in stored and disposed waste	LLW Repository Ltd should review the disposed records for stored waste located in Vault 8. LLW Repository should provide a BAT case for disposal of these items within Vault 8.	This is addressed by references [76] and [77].	-/-
ESC-FI-014	Impact of changing waste composition	LLW Repository Ltd should assess the implication of future waste treatment processes on the settlement of the engineered cap and on the performance of the near	This is within the scope of the Engineering Plan.	See Engineering Plan/ Supported by Activities 31, 54 and 65.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
		field.		
ESC-FI-015	Monitoring of colloids	LLW Repository Ltd should implement a proportionate colloidal material monitoring programme, to ensure that the conclusions reached in the 2011 ESC will remain valid.	We intend to monitor for any radioactive contamination that may be associated with particulates in trench leachate to determine whether further more detailed work is required.	2.4/ See Activities 91, 92, 93, 94 and 95.
ESC-FI-016	Discretisation of the GRM model	LLW Repository Ltd should assess the sensitivity of the outputs from the GRM to the discretisation of the model grid.	We propose to consider model discretisation in general within the Assessment Manual and will apply the requirements to any programs that play a key role in the 2021 ESC.	Applies to all modelling work as a generic issue/ See Activities 100 and 101.
ESC-FI-017	Radiological capacity calculations	LLW Repository Ltd should explore the relationship between disposed inventory and dose or risk to determine the suitability of the linear relationship assumption. Particular emphasis should be placed on C-14. If required, outputs should be fed into the WAC.	An activity is planned to address this requirement.	-/ See Activity 109.
ESC-FI-018	Near field vault and trench experimental	LLW Repository Ltd should propose and implement a near field experimental and monitoring	Near-field monitoring is addressed within our monitoring programme. We	2.4/ See Activities 60, 61, 91, 92, 93, 94 and 95.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
	programme	programme capable of providing sufficient understanding of the vault and trench near field environments to support the ESC throughout the period of authorisation.	have not identified in-situ experiments in the vaults and the trenches as part of the forward programme.	
ESC-FI-019	Monitoring of coastal erosion	LLWR Repository Ltd should develop and implement a coastal evolution monitoring programme. The company should use the output to check assumptions made within the 2011 ESC and to inform continued development of the ESC.	This is part of our proposed approach.	2.4/ See Activities 73, 74, 75, 76, 77 and 78.
ESC-FI-020	Development of a new Low Level Waste Tracking System (LLWTS)	LLW Repository Ltd should develop a new waste tracking system that is fit for purpose for future waste tracking.	LLWR are currently developing a new WTS. The ESC team have been closely involved with the specification and development of the system. The system is due to 'go live' in late 2016 or 2017.	
ESC-FI-021	Learning from development of the ESC	LLW Repository Ltd should undertake a review of learning from the development of the 2002 and 2011 ESCs, so as to inform future major reviews of the ESC.	We have scheduled an activity within the Technical Development Programme. Any output would be an input to the 2021 ESC. We have	3.4/ See Activity 22.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
			already identified the need to review geochemical data and this will feed into a revised Hydrogeology Conceptual Model report and the need for an EPA, on which work has started (see Subsection 3.4).	
ESC-FI-022	Active management of ESC records	LLW Repository Ltd should make sure all ESC related records are actively managed.	A review of records retention and management is planned.	-/ See Activity 18.
ESC-FI-023	Leachate management strategy	LLW Repository Ltd should produce a leachate management strategy that demonstrates the application of BAT to the management of leachate during the period of authorisation. The company should also investigate long-term leachate drainage performance, degradation and failure mechanisms.	This is within the scope of the Engineering Plan.	See the Engineering Plan.
ESC-FI-024	Gas management strategy	LLW Repository Ltd should establish and implement a programme of work to develop a gas management strategy and infrastructure, including collection of necessary monitoring data, for the	This is within the scope of the Engineering Plan.	See the Engineering Plan/ There is also a link to Activity 255.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
		period of authorisation.		
ESC-FI-025	Protection of waste prior to final capping	LLW Repository Ltd should develop and implement a programme of work to develop an optimised container design and restoration sequence that provides adequate protection to waste containers and minimises discharges to the environment.	This is within the scope of the Engineering Plan.	See the Engineering Plan/ There is also a link to Activity 29.
ESC-FI-026	Engineering delivery	LLW Repository Ltd should develop and implement the engineering forward programme to finalise the as-built design so as to allow further construction to begin. This programme should include: • an engineering R&D programme • an engineering performance monitoring programme • the scoping of a proportional Engineering Performance Assessment framework for use in future updates to the ESC.	We are developing an Engineering Plan.	See the Engineering Plan/ There is also a link to Activity 245.

Forward Issue number	Title	Summary of issue	Proposed Resolution	Cross reference (subsection cross reference for the Technical Approach report/ Task reference for this report)
ESC-FI-027	Cap performance assessment	LLW Repository Ltd should undertake further assessment of the performance of the capping system, including consideration of potential failure scenarios. Where appropriate, the company should incorporate the outcome of the investigations into the repository engineering design and updates to the ESC.	This is within the scope of the Engineering Plan. The EPA will address certain aspects.	See the Engineering Plan. EPA described in Subsection 3.2.3.
ESC-FI-028	Improved understanding of the repository erosion process	LLW Repository Ltd should seek to improve its conceptualisation and understanding of the repository erosion sequence.	Conceptual model development work is planned.	3.4/ See Activities 73, 74, 75, 76, 77 and 78.
ESC-FI-029	Management of elicited data	LLW Repository Ltd should develop documented procedures for the future management of elicited data.	This will be addressed in the Assessment Manual and the procedures will then be implemented.	2.7 and 5.1/ See Activities 100 and 101.

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