Review of LLW Repository Ltd's 2011 environmental safety case: Optimisation and engineering

Issue 1, 15 May 2015

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Environment Agency
Horizon house, Deanery Road,
Bristol BS1 5AH
Email: enquiries@environment-agency.gov.uk
www.gov.uk/environment-agency

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T: 03708 506506

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Executive summary

The Environment Agency is responsible for regulating the disposal of radioactive waste in England under the terms of the Environmental Permitting (England and Wales) Regulations 2010. Under its current environmental permit we required LLW Repository Ltd to submit an Environmental Safety Case (ESC) for the Low Level Waste Repository (LLWR) in west Cumbria to the Environment Agency by 1 May 2011.

Our review of the 2011 ESC is documented in a series of reports. This report covers our review of the optimisation and repository engineering areas of the 2011 ESC.

LLW Repository Ltd uses a series of optimisation studies to address questions about the future management of past disposals, criteria for future waste acceptance and suitable ways of packaging and conditioning waste for disposal. The company uses the output from these optimisation studies to underpin its decisions on site development.

LLW Repository Ltd's optimisation studies sought to optimise both engineered barriers and the whole repository design concept in order to minimise radioactive releases to the environment throughout the life of the repository.

LLW Repository Ltd investigated the potential to optimise the site in light of the possibility of coastal disruption after a few 100 to a few 1000 years, for example whether to retrieve certain wastes from the trenches. The company should make sure that actions being taken now do not unduly foreclose future options, for example to retrieve waste from the vaults or trenches, or to further protect the facility.

We concluded that the repository engineering design is optimised in line with the performance objectives set out in the 2011 ESC.

LLW Repository Ltd uses the 2011 ESC to refine the LLWR waste acceptance criteria and develop a number of emplacement strategies to make sure that disposal practices remain optimal. We consider that the proposed waste acceptance criteria and emplacement strategies provide an effective and practical way of achieving optimisation with regards to radiological impacts, with a clear linkage to environmental safety objectives.

Overall, we conclude that LLW Repository Ltd has adequately optimised the repository in terms of both its design and operation, using appropriate processes. However, the documentation of the evolution of the repository design throughout the optimisation process was opaque. This made our scrutiny of the optimisation process challenging. We had to request further clarification on optimisation in several areas, including the proposed operational configuration of vaults, vault sequencing, waste protection and the application of emplacement strategies to waste disposed to, or stored in, Vault 8 and subsequent vaults. LLW Repository Ltd addressed these queries to our satisfaction. Although we conclude that LLW Repository Ltd has presented proposals for an optimised design that are appropriate for the current stage of development of the facility, we note that there is further, more detailed design work to be carried out before construction of the final cap or further vaults begins. There remains scope for further optimisation in the future in a number of areas, for example container design, the protection of waste containers from water and degradation and the capping of the trenches. LLW Repository Ltd has started a substantial forward work programme to progress these issues and as part of our ongoing regulation we will review its progress in this area.

The 2011 ESC presents a Site Development Plan that sets out LLW Repository Ltd's current view of how the repository will be developed as well as providing the baseline against which all performance modelling and assessment throughout the 2011 ESC was carried out.

We consider that the engineering design and the assessment of its performance are the least developed elements of the 2011 ESC. During our review it was apparent that the engineering design presented required further detailed development before implementation. However, we consider that the design is appropriate for the stage of development of the facility.

The 2011 ESC does not set out how the repository design will further develop prior to construction, whilst maintaining consistency with the ESC. We therefore requested further information on this issue. This allowed us to gain sufficient confidence that the presented design could and would be developed further prior to construction to ensure that it will perform as expected. The company has developed a substantial engineering forward plan, which addresses the necessary further work on the design. We consider that the engineering forward plan provides a suitable basis for further developing the repository design.

Projections of the performance of the engineered barrier system in the 2011 ESC are largely based on elicited and modelled information. Although these projections are adequate for the purposes of the 2011 ESC, LLW Repository Ltd should work towards making more use of monitoring and experimental data in the future where demonstrated to be beneficial, reducing reliance on, or supporting elicited and modelled data.

As a result of work subsequent to the 2011 ESC, LLW Repository Ltd has identified that the interim trench cap is performing less well than assumed in the 2011 ESC and that some ISO freight containers in Vault 8 are observed to be in a poor condition. LLW Repository Ltd has further investigated and assessed these issues and has been able to demonstrate to our satisfaction that they can be adequately addressed through implementation of operational improvements or forward work programmes.

Having completed our review, we are confident that LLW Repository Ltd has developed an appropriately optimised engineering design which meets our regulatory requirements. The presented design incorporates systems capable of meeting the required safety objectives including isolation and containment of waste and is at an appropriate level of detail for the stage of development of the facility. However, LLW Repository Ltd will need to undertake further design substantiation and safety assessment work as the details of the design are developed and, before construction, to demonstrate how these systems will behave under both normal operational and fault conditions. We expect this work to make effective use of material performance information, geotechnical data and supporting research and development.

We set out our requirements for future development and implementation of the engineering design in a number of Forward Issues. We will monitor progress of this work at agreed regulatory review points.

Contents

1. Introduction

1.1. Introduction

The Environment Agency is responsible for regulating the disposal of radioactive waste in England under the terms of the Environmental Permitting (England and Wales) Regulations 2010 (EPR10) as amended (and before that was responsible under the terms of the Radioactive Substances Act 1993 (RSA 93) as amended). In accordance with government policy, we periodically review environmental permits for the disposal of radioactive waste. During this process we consider a wide range of information, including the conclusions from our reviews of the Environmental Safety Case (ESC) produced by the operator of the disposal facility concerned.

The Low Level Waste Repository (LLWR) near Drigg, Cumbria is the UK's primary facility for the disposal of solid low level radioactive waste (LLW). As a result of a major review of the LLWR ESC undertaken between 2002 and 2005, we included a requirement in the current LLWR environmental permit for the operator, LLW Repository Ltd, to 'update the Environmental Safety Case(s) for the site covering the period up to withdrawal of control and thereafter' (Schedule 9 Requirement 6). We received the updated ESC on 1 May 2011 (the 2011 ESC). We have subjected this ESC to a rigorous technical review using suitably qualified and experienced personnel.

The aims of the review were:

- to determine the adequacy of the 2011 ESC as a submission against Schedule 9 Requirement 6 of the current LLWR environmental permit
- to provide an Environment Agency view on the technical adequacy of the 2011 ESC
- to use as a major input to a forthcoming regulatory decision on permitting the LLWR for further disposal of radioactive waste
- to identify potential areas of improvement to the 2011 ESC, to guide LLW Repository Ltd

In our review, we have considered whether the 2011 ESC is based on sound science and engineering and meets the principles and requirements set out in the most recent environment agencies' guidance on requirements for authorisation (GRA) of near-surface disposal facilities (Environment Agency et al. 2009). The GRA explains the requirements that we expect an operator to fulfil in applying to us for a permit to operate such a facility. It includes our radiological protection requirements and provides guidance on the nature of the ESC we would expect to see.

On 28 October 2013 LLW Repository Ltd made an application to the Environment Agency to vary the existing environmental permit under the EPR10 to dispose of further waste at the repository. This application covered an extended disposal area, which would allow sufficient capacity for the LLWR to accept a significant proportion of the UK's LLW predicted to be generated out to around 2130 (excluding lower activity LLW that could be diverted to other facilities). The application is in line with the proposals set out in the 2011 ESC, incorporating any subsequent modifications since the ESC submission. The proposal is to design, operate and close the facility in accordance with the 2011 ESC and subsequent changes described within the environmental permit application.

Our review of the 2011 ESC is intended to provide technical underpinning of our decision on LLW Repository Ltd's permit variation application. We will only permit further disposals at the LLWR if we are convinced that these disposals will not present an unacceptable risk to people and the environment. That is, the 2011 ESC needs to demonstrate that the short-term and long-term environmental impacts from past and proposed future disposals, taken together, will be acceptable.

1.2. The 2011 ESC submission

LLW Repository Ltd submitted the 2011 LLWR ESC to the Environment Agency on 1 May 2011. The 2011 ESC comprised the following hierarchy of documents:

- Level 0 - A non-technical summary, not aimed at regulators

- Level 1 - A single top level main report (143 pp) summarising the main arguments and the broad lines of evidence supporting them
- Level 2 - 16 topic reports (of 50 to 250 pp each) setting out in more detail the evidence to support the main arguments
- Key Level 3 - 95 underpinning reports (mostly 50 to 200 pp) identified by LLW Repository Ltd as being ‘key’
- Other Level 3 - Several hundred other references referred to in the above documentation but not identified as ‘key’

The Level 1 and 2 documents form the core of the 2011 ESC, with additional detailed information contained in Level 3 documents. During our review, we needed to extensively scrutinise many of the Level 3 documents in order to understand the safety arguments. The Level 0, 1 and 2 documents plus the 'key' Level 3 documents are available from relevant public registers and, at the time of writing and during our consultation period, from the LLW Repository Ltd internet site at: http://llwrsite.com/national-repository/key-activities/esc/esc-documentation/

LLW Repository Ltd has informed us that it is continuing to investigate potential options for the future design, operation and long-term management of the LLWR. We are also aware that the Nuclear Decommissioning Authority (NDA) and Site License Companies (SLCs) have been reviewing their procedures for estimating and reporting future LLW arisings to improve the accuracy of future inventory data. However, the scope of our review has comprised only the 2011 ESC as submitted, together with supporting documentation and further information provided up to and including the date of the environmental permit variation application made in October 2013. Any subsequent proposals to change the basis of the ESC will be addressed separately.

1.3. The review process

We have carried out a detailed technical review of the 2011 ESC. The review comprised an assessment of whether the ESC arguments, outlined in the Level 1 report, adequately address the requirements of the GRA and whether the evidence provided supports the arguments.

We have reviewed lines of evidence and underpinning information, judged by our suitably qualified and experienced reviewers to be of importance to the ESC to the depth considered necessary to determine their validity, including tracing data and assumptions back to original empirical evidence. We have pursued other lines of evidence and underpinning information considered to be of less importance in less depth. We have completed a detailed review of the Level 1, Level 2 and important Level 3 documentation, also referring to other Level 3 documents to the extent that they underpin the ESC.

Environment Agency (2015a) provides further information on our approach to the review and the process we have used.

The primary test of the acceptability of the 2011 ESC as a whole, or of an individual document, was whether it meets Schedule 9 Requirement 6 of the current site permit and satisfies the relevant principles, requirements and guidance in the GRA. Where potential deficiencies or other issues were identified during our review, they were categorised as follows:

- A Regulatory Issue (RI) is a deficiency sufficiently serious that, unless or until it is resolved, we will either: (a) not grant a permit; or (b) grant a permit constrained by major limiting conditions (as distinct from information or improvement conditions) defined by us to mitigate the consequences of the RI.
- A Regulatory Observation (RO) is a deficiency not sufficiently serious to prevent our issuing a permit but sufficiently serious that, unless or until it is resolved, we will include an improvement or information condition in the permit requiring defined actions on defined timescales to resolve it (or to demonstrate suitable and sufficient progress towards resolving it). Related ROs may be grouped into a single improvement or information requirement. (We may also apply minor limiting conditions in the permit until it has been resolved.) An RO can become an RI if the condition is not met.

- A Technical Query (TQ) is a deficiency not sufficiently serious for us to require defined action by LLW Repository Ltd but sufficiently significant for us to request action. An individual TQ is unlikely to become an RO even if not addressed, but a number of unresolved TQs may accumulate into an RO.
- Any other further information or points of clarity considered to be worth requesting of LLW Repository Ltd are designated as Minor Comments. LLW Repository Ltd was requested, but not required, to provide responses to these to enable us to conclude our review of the 2011 ESC. However, LLW Repository Ltd did provide responses whenever requests for further information were made.

For each RI, RO and TQ we have generated an Issue Resolution Form (IRF), which records and tracks the issue and its resolution. IRFs are detailed records of concerns raised as part of our review of the 2011 ESC. Each IRF defines one or more actions. We have expected LLW Repository Ltd to provide a substantive response to the action(s) specified on the IRF by a specified date(s).

The IRFs form a substantial element of our review output. LLW Repository Ltd has provided responses on each IRF; where appropriate this may be a summary of the response, referring to more detailed information in supporting documentation. Each IRF also records our evaluation of the response. An issue has only been closed out when we have determined that the response from LLW Repository Ltd adequately addresses it. Where appropriate, we raised further actions or queries so we could close the IRF. All IRFs have now been closed.

We recognise that the 2011 ESC is a complex submission involving a wide range of technical assessments that will evolve and improve in the future as technology and understanding advances. Certain details will also be developed further as the site advances, for example towards construction of the final engineered cap over the waste. Within our review we therefore identify important areas which we believe will benefit from further work, development or clarification in the future. These areas are identified as Forward Issues (FIs). These represent areas of work that we believe it is important for LLW Repository Ltd to progress as part of its forward improvement plan. FIs address areas where we expect continued improvement in the ESC and its implementation. We will require LLW Repository Ltd to engage with us on these FIs, to put in place formal mechanisms to track and address them and, as necessary, incorporate work to address them in its forward programmes of work and report to us on progress and when it believes the FIs have been fully addressed. We will expect the outcome of FIs to be considered within any subsequent updates to the ESC.

Throughout the review, we also made a number of specific recommendations to LLW Repository Ltd. Recommendations represent areas where we see scope for possible improvement or development, but which are relatively minor in nature relative to FIs. These recommendations are numbered and highlighted in this document. As a matter of good practice we expect LLW Repository Ltd to address these recommendations and will expect a mechanism to be put in place to track them.

It is important to note that these FIs and recommendations do not represent the only areas of work that we will expect LLW Repository Ltd to progress and are not intended to represent a comprehensive scope for forward work. We will require the company to develop its own forward programme of work as necessary to maintain and improve the ESC; our FIs and recommendations should only form part of that programme. LLW Repository Ltd’s forward programme of work must be informed by a wide range of inputs, for example monitoring data, research and development, improvements in technology and continuous improvement.

This report is necessarily focused on the negative, bringing out areas where we have raised concerns, or have remaining concerns, or expect further action or permitting requirements. We do not necessarily comment on areas we are content with and we do not list everything we have reviewed. The length of discussion on any particular topic may depend on the degree of interaction between us and LLW Repository Ltd and does not necessarily reflect the significance of the issue. However, we have made positive comments where we believe that the treatment of issues represents good practice.

1.4. ESC review deliverables

The output from our review of the 2011 ESC is a series of review reports that will provide technical underpinning to future permitting decisions. The document hierarchy is illustrated in Figure 1.

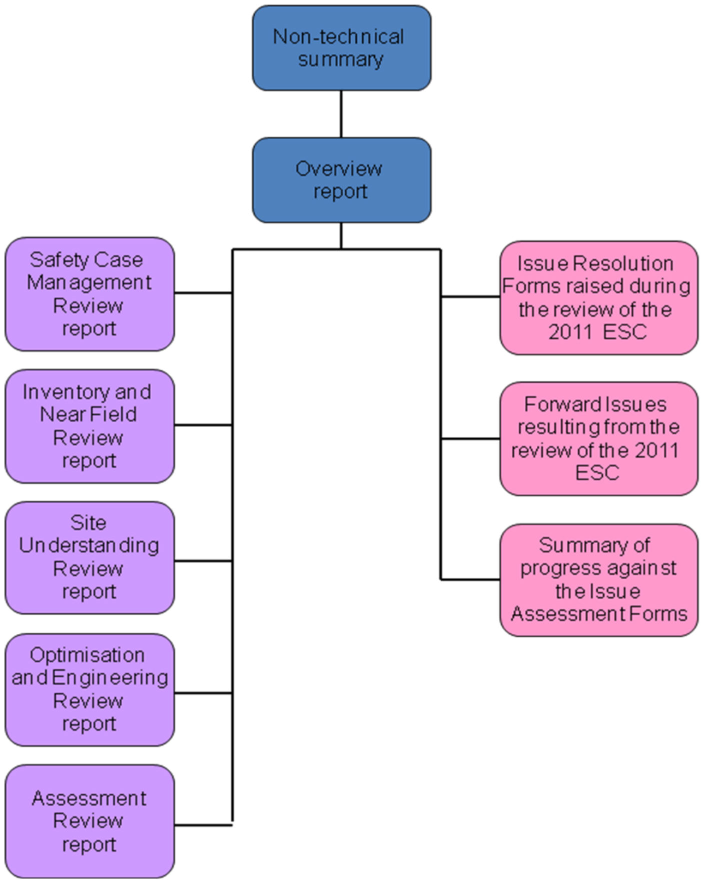

Figure 1 The Environment Agency review of the 2011 ESC: Document structure

The main document is the overview report of the technical review (Environment Agency 2015a). It provides our conclusions on the extent to which LLW Repository Ltd's 2011 ESC demonstrates to our satisfaction that existing and proposed future disposals meet the requirements set out in the GRA, as well as whether Schedule 9 Requirement 6 has been met satisfactorily. The overview report includes background information on the history of the LLWR and regulatory requirements. It also describes our review process in greater detail.

The overview report is supported by 5 technical review reports, which provide more detailed conclusions on the technical adequacy of the 2011 ESC as a basis for permitting future disposals. These reports cover the following topic areas: Optimisation and Engineering (this report); Safety Case Management (Environment Agency 2015b); Inventory and Near Field (Environment Agency 2015c); Site Understanding (Environment Agency 2015d); and Assessments (Environment Agency 2015e). The IRFs resulting from each of the topic area reports are collated in a standalone report (Environment Agency 2015f).

Forward Issues that are raised as a result of our review of the 2011 ESC are also collated in a separate report (referenced as ESC-FI-xx) (Environment Agency 2015g). We will agree with LLW Repository Ltd when and how it addresses these issues through our normal regulatory interactions and will track progress made to resolve them.

We documented concerns from our review of the previous LLWR Operational Environmental and Post-Closure Safety Cases (the 2002 ESCs; British Nuclear Fuels Ltd (BNFL) 2002a,b) on Issue Assessment Forms (IAFs), which are similar to the IRFs. We report our review of LLW Repository

Ltd’s progress in addressing actions raised in the IAFs in Environment Agency (2015h). Any actions that we consider have not been fully addressed in the 2011 ESC are taken forward in the FIs or recommendations.

We have also prepared a non-technical summary of our review of the 2011 ESC (Environment Agency 2015i).

Together the documents describing the review of the 2011 ESC summarise the findings of our review and provide information to support consultation on our draft decision about the future permit for the LLWR.

We welcome any comments on our review findings. Such comments could be provided in response to our forthcoming consultation on permitting the LLWR.

2. Our Review

2.1. Overview

This report is one of 5 technical assessment reports that support the overview report of our review of the 2011 ESC and cover the main topic areas of the ESC in more detail. It covers the optimisation and engineering areas of the 2011 ESC. Our review focused on the Level 2 and Level 3 reports, however, we had to request further information not included in the 2011 ESC submission in some areas. We also held several workshops with LLW Repository Ltd to discuss engineering and monitoring details.

We raised a series of IRFs as part of our review. This was to challenge, clarify or seek further evidence in areas where we considered the case submitted fell short, for example, where we considered that the requirements of the GRA were not fully addressed, or where we took the view that technical arguments or conclusions required further evidence to support them. These IRFs are summarised in Appendix 1 of this report and presented in full in a separate report (Environment Agency 2015f).

LLW Repository Ltd satisfactorily addressed all the IRFs raised in the optimisation and engineering area during the course of our review and we have closed them. Nevertheless we have identified a series of recommendations and FIs where we consider there is scope for LLW Repository Ltd to make further improvements or pursue developments to the ESC in the future. Whether we made a recommendation or raised a FI depends on the environmental consequences in the absence of any further work. Tables summarising the recommendations and FIs are respectively presented in Appendix 2 and Appendix 3 of this report. We also assessed whether the information presented was sufficient to address technical issues that we raised previously in our assessment of the 2002 ESCs (Environment Agency 2005a). A summary of how LLW Repository Ltd has addressed these issues can be found in a separate report (Environment Agency 2015h).

The following sections detail our review, focussing on those areas we deemed important to the 2011 ESC. The first section covers our review of the application of optimisation, while the second deals with wider aspects of the engineering design presented in the 2011 ESC. Our review focuses on the assessment work covering the LLWR Reference Disposal Area (RDA), which comprises the trenches and Vaults 8 to 14. Separate sections are provided addressing the Extended Disposal Area (EDA), which comprises the RDA plus further Vaults 15 to 20.

The main engineering aspects of the repository include:

- Construction of engineered vaults, eventually filling the northern part of the site up to a line continuous with the southerly end of the trenches in the RDA. Future vaults will be designed with side walls which only extend to a nominal 1 m height to prevent vault overtopping and incorporating engineered passive drainage arrangements.
- The grouted ISO freight container waste form, which provides a barrier to contaminant releases and a structural support for the final engineered cap.
- Progressive construction of a final cap over the vaults and trenches. The final cap includes a gas venting system as well as elements designed to promote the long-term functioning of the cap.
- Construction of a low permeability cut-off wall to tie into the final cap perimeter and the existing cut-off wall at the northeast corner of the site. The cut-off wall is designed to minimise groundwater flow into the waste and direct any vault discharges to groundwater away from the near-surface environment.
- Collection, monitoring and discharge of leachate from the trenches and vaults to sea via the Marine Holding Tank and Marine Pipeline during the period of authorisation.
- The management and restoration of the interim trench cap before the placement of the final cap. This will entail development of an optimised restoration strategy.

The engineering design presented in the 2011 ESC, in particular the post-closure engineering, is to an extent conceptual[1] in nature; the design detail will be developed progressively. In the engineering section we make comments on the conceptual repository design that explore aspects of the design and relate directly to meeting the requirements of the GRA. These comments are provided to assist LLW Repository Ltd by informing it of our regulatory expectations during the further development of a detailed design.

2.2. Optimisation

Optimisation is defined in the glossary of the GRA as 'the principle of ensuring that radiation exposures are as low as reasonably achievable (ALARA) in the given circumstances'. Optimisation is a fundamental concept in the GRA, where it is expressed both as a Principle and a Requirement:

- Principle 2: 'Optimisation (as low as reasonably achievable). Solid radioactive waste shall be disposed of in such a way that the radiological risks to individual members of the public and the population as a whole 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 radiological risks to other living organisms and any non-radiological hazards.' (GRA paragraph 4.4.1)
- Requirement R8: Optimisation. 'The choice of waste acceptance criteria, how the selected site is used and the design, construction, operation, closure and post-closure management of the disposal facility should ensure that radiological risks to members of the public, both during the period of authorisation and afterwards, are as low as reasonably achievable (ALARA), taking into account economic and societal factors.' (GRA paragraph 6.3.56)

The Level 2 Optimisation and Development Plan (LLW Repository Ltd 2011a) summarises the evidence relating to LLW Repository Ltd's optimisation approach in developing the LLWR. A series of Level 3 optimisation reports (Harper and Dickenson 2011, Lean et al. 2011, Penfold et al. 2010 and Paulley and Egan 2011) capture the approach in more detail by describing specific optimisation studies. Our review covers LLW Repository Ltd's general approach to optimisation as set out in the Level 2 report, together with relevant Level 3 documents. We have also reviewed issues relevant to optimisation across the 2011 ESC; these include strategies for institutional control, packaging innovations and container improvements.

LLW Repository Ltd uses its optimisation work to underpin its decisions on site development. The Site Development Plan (SDP) sets out the site development sequence, the repository engineering design, the operational philosophy, and restoration of the completed repository, all of which have been subjected to optimisation (LLW Repository Ltd 2011b). Our review covers the use of optimisation to inform the SDP. LLW Repository Ltd's design approach is focused on the most likely anticipated circumstances and engineering is kept as simple as possible within strategic constraints. Wider decisions about the continued use of the LLWR facility for radioactive waste disposal are constrained and informed by government's policy for managing LLW (Defra et al. 2007) and thus not subject to optimisation in the context of the ESC.

In our review of the previous (2002) LLWR ESCs, we concluded that 'the 2002 safety cases include insufficient consideration of optimisation and risk management, to demonstrate that impacts will be as low as reasonably achievable (ALARA)' (Environment Agency 2005).

In these 2002 ESCs, BNFL, the then Site License Company, presented a design concept for the repository broadly similar to that presented in the 2011 ESC. However, LLW Repository Ltd's optimisation work has developed the design significantly since 2002. It has included work on the

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[1] By 'conceptual' we mean that the 2011 ESC has provided evidence that allows us to take a view that the required performance can be provided by an engineering design that could be constructed. However, such a design has not yet been fully developed in all its details and LLW Repository Ltd will need to carry out substantial further detailed development and optimisation work before we can accept that the engineering design will meet environmental safety requirements.

modular vault design and studies supporting the 2008 response to Schedule 9, Requirement 2 of the LLWR environmental permit, which provided an update on LLW Repository Ltd's performance assessment and its strategy for optimisation at the LLWR (Williams and Proctor 2007). Optimisation work carried out since the 2008 response to Schedule 9, Requirement 2 is described in Paulley and Egan (2011) and LLW Repository Ltd (2011a).

In addition to government policy (Defra et al. 2007), LLW Repository Ltd's optimisation process has been framed by the environmental context of the site, past decisions taken at the site regarding trench and vault disposals and the physical constraints of the LLWR site within the current planning permission, or that sought for the future[2]. It is appropriate that the optimisation process did not include the consideration of other potential disposal sites or alternative locations as optimisation applies only to the chosen location of the activity. This framing is important, since a new LLW disposal facility optimised for a different setting may look quite different from the current optimised LLWR design.

We require the optimisation process to continue throughout the design, construction and operation of the repository. Optimisation carried out as part of the engineering design development and justification process may not necessarily be reported to us routinely step by step. However, where changes have, or might be seen to have, significant repercussions for the management of disposal of radioactive waste by burial, LLW Repository Ltd will be required to notify us of those changes and, as necessary, we will subject these changes to regulatory review. We expect these changes to take place within a formalised management of change framework. Links between the developing engineering design and the ESC should be clearly documented in formal procedures (**Recommendation O&E1**).

Since the submission of the 2011 ESC, optimisation studies have continued either as a result of planned concept development or as a result of the need to make improvements identified by LLW Repository Ltd and/or us during our review of the 2011 ESC. In our review, we have taken account of information submitted up to October 2013.

LLW Repository Ltd reports on its optioneering studies in the following areas:

- management controls and interventions relating to past disposals
- management and engineering controls over future waste disposals to the LLWR, including treatment and packaging, waste acceptance and methods for waste emplacement
- passive engineering measures contributing to the environmental safety performance of the LLWR before and after surrender of the permit, taking account of the functional role of engineering features in the overall environmental safety strategy, as well as their design and the timing of their implementation
- active management controls over environmental safety performance, including implications for discharges during the period of authorisation, as well as arrangements for the LLWR site after the period of authorisation
- other studies relating to the optimisation of operational procedures such as waste emplacement strategies and post-closure institutional arrangements

LLW Repository Ltd describes its approach to optioneering for the engineering design in Paulley and Egan (2011). Figure 2 illustrates the approach used for the optimisation of design strategies and individual components.

[2] During our review, LLW Repository Ltd submitted a planning application for the development and restoration of the repository covering the RDA. At the time of writing a decision on planning permission has not been reached.

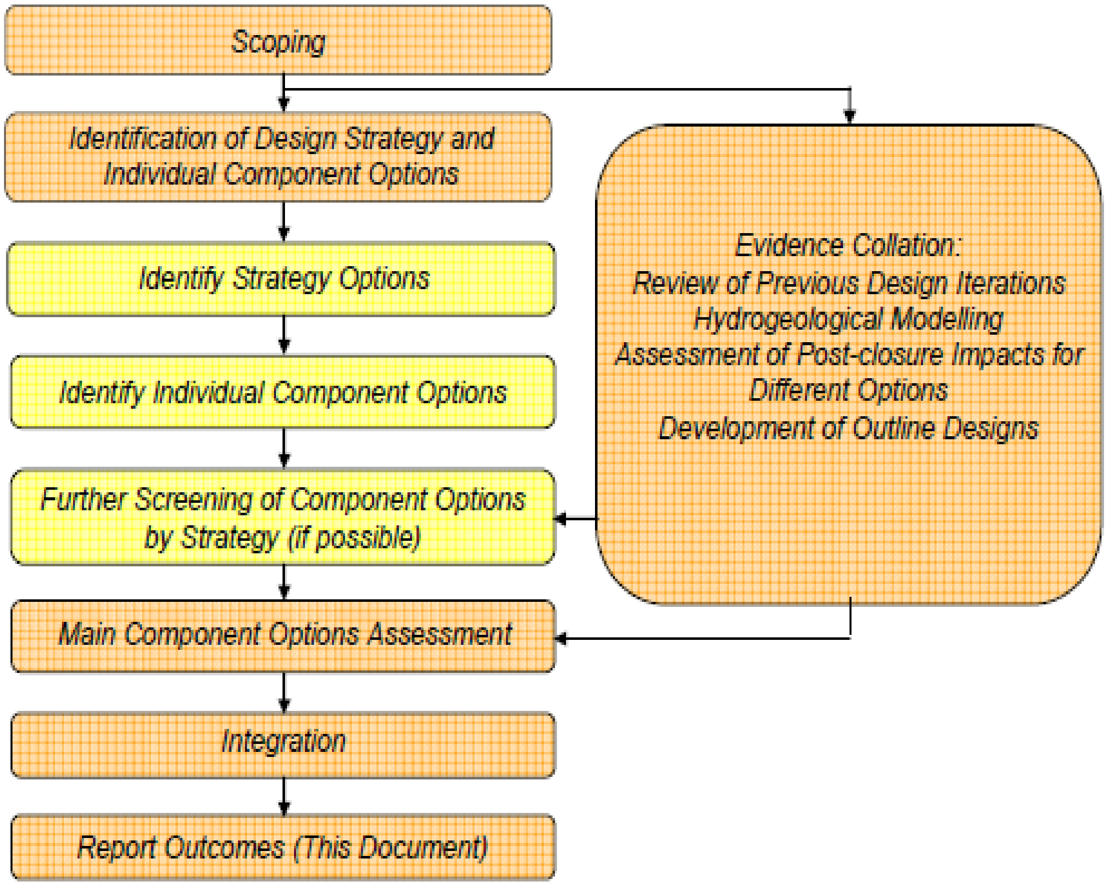

Figure 2 Overview of LLW Repository Ltd's optimisation process (from Paulley and Egan (2011))

The process consists of identifying the design strategy and options for individual components of the engineering design, followed by assessing each of these design options and then integrating the chosen option into the overall design.

Breaking the disposal system down into tractable study areas and work packages is a practical way of optimising for radiological protection. However, an important element of an integrative, iterative process is to stand back, look at the disposal system as a whole and ask the question, 'could anything more be done?'.

We consider it important that in future updates of the ESC LLW Repository Ltd should revisit the optimisation decisions presented in the 2011 ESC to make sure they remain valid. Any review should where possible apply optimisation on a repository scale as well as at a component level. Specifically, alongside the engineering forward programme currently being implemented by LLW Repository Ltd (for example, Shaw 2013), we recommend that the optimisation of the repository as a whole is revisited. This might include re-appraisal of existing decisions and discarded options to see whether design, engineering or operational choices for the trenches and vaults continue to represent an optimised solution for the radiological performance of the LLWR taken as a whole (**Recommendation O&E2**).

Optimisation of radioactive waste disposal facilities requires an approach that takes into account both operational and post-closure safety considerations. The Environment Agency does not regulate operational safety: rather, this is regulated by the Office for Nuclear Regulation (ONR) under LLWR's nuclear site licence. The 2011 ESC rightly does not discuss how LLW Repository Ltd manages operational safety, which is addressed in the site's nuclear safety cases. However, the 2011 ESC also does not always clearly address how any operational safety issues that also affect operational environmental safety and post-closure environmental safety are resolved to achieve an optimum outcome overall. This is an area that could benefit from more clarity in decision making, for example how operational safety issues are factored into decisions on the overall optimised design. Operational safety issues may be particularly important in relation to the movement and stacking of containers. For example, to achieve an optimised container stacking arrangement, consideration will be needed of worker safety during the movement and placement of stored containers. To assist in the continuing optimisation process we recommend that future updates of the ESC should provide greater clarity on how operational safety issues and decisions are factored in to the optimised design (**Recommendation O&E3**).

LLW Repository Ltd presents the outputs from decision making workshops and outlines the subsequent development of optimised designs (Paulley and Egan 2011). In most cases there is little discussion on how decisions are reached or the provision of detailed records of decisions and meetings. Because of the extensive history of design optimisation we consider it vital to make sure that the continuing optimisation process is fully informed of previous decisions. We understand that meeting records have been produced but, due to the lack of information provided with the 2011 ESC decision making process, LLW Repository Ltd has not presented a comprehensive picture of the optimisation process historically. This made our review of the optimisation process difficult. For example, we found the substantiation of significant changes to the engineering design such as the final cap restoration shape and the future vault drainage system to be poorly described.

For future updates of the ESC, we would like to see improvements to the documentation and description of how decisions were made and progressed, as well as ensuring easy access to the information made available to workshop attendees. For the most significant aspects of the engineering design, future iterations would benefit from a narrative describing past optimisation decisions that took place between the 2002 ESCs and the 2011 ESC (**Recommendation O&E4**).

LLW Repository Ltd (2011a) quotes from the GRA (paragraph 6.3.58), which states that optimisation is '...about finding the best way forward where many different considerations need to be balanced. Relevant considerations include, for example, economic and societal factors, and the requirement to manage any non-radiological hazards... Although reducing radiological risk is important, it should not be given a weight out of proportion to other considerations...the best way forward is not necessarily the one that offers the lowest radiological risk'. While this is true, the company should in future make the weight attributed to all factors considered in the optimisation process more explicit (whether qualitatively or quantitatively) with greater clarity on how decisions about option choices have been reached (**Recommendation O&E5**).

2.2.1. Management controls and interventions relating to past disposals

A baseline assumption in the 2002 ESCs was that all past waste disposals in the trenches would be dealt with by post-closure engineering provisions such as a cap, cut-off wall and leachate systems. Because the 2002 PCSC (BNFL 2002b) projected that radiological impacts would exceed relevant regulatory guidance level (set at the time as a risk target of 1 in a million per annum) over 10s of 1000s of years, we sought further investigations to identify strategies to reduce the radiological impact significantly.

In Requirement 2 of Schedule 9 of the current environmental permit for the LLWR, we required that the operator should undertake 'a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site'. LLW Repository Ltd's response consisted of several supporting studies and included a consideration of both waste retrieval and in situ remediation as options for the management of hazards from past disposals to the trenches (Baker et al. 2008). In our response we indicated that further work would be required to provide a systematic analysis and comparison of options to support a comprehensive ESC (Environment Agency 2009). We reviewed the arguments set out in the 2011 ESC and determined whether they meet the GRA environmental safety objectives. We discuss our findings below.

Trench waste retrievals

The high assessed doses and risks to people and the environment resulting from past trench disposals were an important safety issue in the 2002 PCSC (BNFL 2002b). LLW Repository Ltd subsequently identified and assessed potential mechanisms to optimise the facility and determine that these doses are ALARA, with either wholesale or selective retrieval of waste (Bloomer et al. 2009). The company built on this work in the 2011 ESC and presented an assessment of options for selective retrievals of significant trench waste disposals. We found LLW Repository Ltd's review of selective trench retrievals options to be appropriate, although we note that in some areas information used in the assessment has subsequently been updated. The company has demonstrated that calculated doses are consistent with regulatory guidance levels and as a consequence we do not consider this a significant issue.

However, in ESC-TQ-ASO-007 we questioned the disposal costs of retrieved waste that it is assumed would need to be sent to a geological disposal facility due to the lack of any other suitable facility at present. Updated costs were provided by LLW Repository Ltd based on figures recently published by the Radioactive Waste Management Directorate[3] (NDA 2012). The company concluded that costs of trench waste retrieval and subsequent waste disposition remain grossly disproportionate to the benefit gained and we agree with this conclusion.

We note that the costs associated with the subsequent disposal of higher active waste recovered from the trenches reflect the current lack of an alternative suitable disposal facility. During the period of authorisation, a disposal route for higher active waste may become available, thus changing the assumed cost. Because these costs reflect the current policy in England for higher active waste disposal we recommend that LLW Repository Ltd should reassess the cost model for retrieval and re-disposal of certain trench waste if the policy for disposal of higher activity waste changes (**Recommendation O&E6**).

We consider that the optimisation work on trench disposals presented in the 2011 ESC has taken appropriate account of potential management options and improved understanding of site evolution and expected timescales for site erosion. LLW Repository Ltd concludes that there is no current driver for retrieval or remediation based on dose and risk criteria. We have reviewed the benefits and detriments of retrievals presented by LLW Repository Ltd and agree that at present the detriments of wholesale or selective retrieval of significant waste disposals are disproportionate when compared to the benefits.

LLW Repository Ltd concludes that no intrusive remediation of the trenches is warranted, but that active leachate management, future closure engineering and the renewal of the interim trench cap will optimise the long-term environmental performance of the trenches. We are satisfied that the evidence presented supports this conclusion.

Vault waste disposal and retrievability

The LLWR has been designed and optimised as a disposal facility for radioactive waste, as opposed to a storage facility. Radioactive waste is disposed of in the facility with the understanding that there is no intent to retrieve it, which is in line with current government policy. Both Vault 8 and Vault 9 have been designed and constructed for the purpose of radioactive waste disposal. However, currently only Vault 8 is permitted for radioactive waste disposal and, within Vault 8, permission has only been granted for disposal of waste in the lower 4 rows of waste containers (some are stacked higher in rows 5 and 6). Waste currently held at the LLWR in rows 5 and 6 of Vault 8 and within Vault 9, are stored pending the availability of a disposal route.

LLW Repository Ltd has submitted an application (LLW Repository Ltd 2013g) for an environmental permit variation to allow further disposal of waste at the site, including into Vault 8, Vault 9 and subsequent vaults. Prior to the disposal of any stored waste we require LLW Repository Ltd to demonstrate that this is consistent with any extant environmental permit and the 2011 ESC and that disposal at the LLWR is demonstrated to be an option that is consistent with the use of best available techniques (BAT), in other words, that it is the optimal management solution. The decision whether or not to dispose of stored waste in-situ (waste currently stored in rows 5 and 6) is a separate, but related decision to that required to determine the maximum container stack height within the vaults, which is subject to ongoing engineering assessment.

[3] Now Radioactive Waste Management Limited (RWM).

However, both of these decisions must be factored into the optimised decision on final stack height.

We raised an IRF (ESC-RI-ASO-003) that sought assurance that current and future development of the LLWR would not preclude the possibility of waste retrieval, nor make retrieval unnecessarily difficult for future generations, or prevent the placement of sea defences should they be considered necessary in the future. LLW Repository Ltd notes that retrieval of waste from the vaults is within current industrial knowledge and capability (Egan 2011a). LLW Repository Ltd states that, because of the limited structural lifespan[4] of the grouted waste containers, retrieval of the containerised waste in the vaults would most likely be carried out using bulk excavation techniques rather than by attempting to remove individual containers intact. LLW Repository Ltd's review of the vault design concluded that there is nothing in the current design or future plans that would preclude future generations from retrieving waste. Equally, there is nothing to prevent development of sea defences adjacent to the site, either specifically in relation to the LLWR, or as part of wider plans for coastal management in Cumbria. Because of the predicted likelihood of coastal erosion of the site, it is important that retrieval of waste in existing and future vaults is not unnecessarily foreclosed; this should be taken into consideration in all key operational and design optimisation decisions (**Recommendation O&E7**).

The assessment of waste retrievability presented in the 2011 ESC was based on current technologies and methods, we therefore ask that LLW Repository Ltd should keep developments in relevant remediation and remote handling technologies under review. We recommend that the company reviews the viability of selective waste retrievals and the associated environmental safety arguments in future updates of the ESC (**Recommendation O&E8**).

Performance of the interim trench cap

The restoration sequence presented in the 2011 ESC assumes that the current interim trench cap will perform in a manner that is consistent with the use of BAT and is therefore optimised for the period until it is replaced with a final capping system.

LLW Repository Ltd has characterised the performance of the interim cap on an annual basis since 2007 using a water balance approach in support of Schedule 9 Requirement 7 of the LLWR environmental permit (BNFL 2007, LLW Repository Ltd 2008, 2009, 2010, 2013a and Jefferies 2011). This work has shown that the interim trench cap is performing significantly less well than assumed in the 2011 ESC, with around 50% of the hydrologically effective rainfall (HER) being unaccounted for in the measured trench cap run-off (LLW Repository Ltd 2011c and Henderson and Bechelli 2011). In ESC-TQ-INF-018 we sought alignment of the trench cap performance assumptions used in the 2011 ESC with the observed performance of the trench cap. The environmental implications of the observed interim trench cap condition are discussed in Environment Agency (2015c).

LLW Repository Ltd's preferred strategy for the management of the interim trench cap was to reduce infiltration by the re-sealing and repairing of all the trench probe perforations using modern construction quality assurance (CQA) approaches, together with the re-profiling of depressions in the cap surface, laying of field drains and other opportunistic improvements. This would be followed by improved monitoring of the water balance. LLW Repository Ltd started these works in winter 2013 and has completed repairs to all of the trench cap probes. During this work, the company encountered significant faults in the trench cap membrane. As a result the adopted approach was stopped, with further optimisation work now planned to take account of the observed membrane conditions. At the time of writing optimisation studies are ongoing. LLW Repository Ltd has stated that it will maintain a BAT approach until the installation of the final engineered cap.

We will monitor and assess the developing strategy for the management of the interim trench cap and its consistency with an optimised repository restoration sequence. In any environmental permit we require LLW Repository Ltd to demonstrate the application of BAT and optimisation on a repository scale.

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[4] In this context structural lifespan relates specifically to container lifting safety.

Past disposals of discrete items and particles

We and LLW Repository Ltd identified the need to assess radiological impacts to potentially exposed groups (PEGs) as a result of coastal erosion and human intrusion, related to discrete items[5] and high activity particles that may be within waste (Environment Agency 2015e). Because the GRA does not explicitly provide regulatory guidance for the assessment of discrete items and particles, we issued advice to Environment Agency assessors on the assessment of these impacts (Smith 2014). For future disposals, LLW Repository Ltd has applied this advice to develop new waste acceptance criteria (WAC) (LLW Repository Ltd 2013b). However, the company has not demonstrated optimisation, or assessed the retrieval of discrete items and high activity particles that may be in past disposals to the trenches and Vault 8, nor of waste currently stored in Vaults 8 and 9. We understand that the company has subsequently commenced work to address this issue.

Discrete items and high activity particles present in the trench disposals will not necessarily correspond to the high activity waste streams assessed in the 2011 ESC trench retrieval studies. Should LLW Repository Ltd consider that the retrieval of discrete items carrying a significant burden of radioactivity from the LLWR may not be an optimised approach (see Smith 2014), then it should submit an ESC[6] that makes this argument to the Environment Agency. This could be due to the fact that any or all of the following may not be adequately known: (a) the nature of the items; (b) the burden of radioactivity the items carry; and (c) the location of the items within the LLWR. Such an ESC should identify all items that it covers to the extent that the available records make this possible. We require this assessment to be carried out before the placement of the final cap. In ESC-FI-013 we ask LLW Repository Ltd to respond to this statement and if appropriate submit proposals for the retrieval of these items. This assessment could utilise many of the assumptions used in the trench retrieval studies (LLW Repository Ltd 2011a) as well as using waste records and the outputs of the RECALL exercise (Hickford and Smith 2011). The completion of ESC-FI-013 will help LLW Repository Ltd to demonstrate an optimal approach for past disposals that takes account of the potential dose reduction from the retrieval of high activity discrete items. We further discuss the assessment aspects of discrete items and high activity particles in Environment Agency (2015e).

2.2.2. After the period of authorisation

In the 2011 ESC, LLW Repository Ltd presents optimised designs and management approaches to minimise the consequences of events and processes that might or will happen after the period of authorisation. These measures are intended to:

- ensure passive measures and features are in place to restrict access, to prevent or mitigate radiological consequences
- put in place an approach to land use and information management that is sustainable after surrender of the permit

Site management after the period of authorisation

The GRA requires that optimisation measures be considered for the whole lifespan of the repository. Because of the high risk of coastal erosion at some point in the future, the 2011 ESC investigated potential optimisation measures that could be implemented to minimise the radiological consequences.

The SDP states that the repository will be fully restored before the end of the period of authorisation (LLW Repository Ltd 2011a). While the environmental permit is in effect, access to the repository will be restricted. We and LLW Repository Ltd assume that, after the period of authorisation, access will be unrestricted. The 2011 ESC restoration design (LLW Repository Ltd 2011b) does not preclude any subsequent use of the site, but it also does not take account of, and

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[5] A discrete item is a distinct item of waste that has become exposed and that, by its characteristics, is recognisable as unusual or not of natural origin and could thus be a focus of interest, out of curiosity or because of its potential for recovery and recycling/re-use.

[6] We note that the ESC need not be fully revised and only relevant parts of the ESC need be presented.

optimise for, any likely subsequent use. As part of future cap design and end point optimisation we would like to see consideration of the end state for the capped repository. This might include habitat objectives and planning permission considerations, such as final landscape design. Although we consider this to be an issue of low importance and also subject to significant uncertainty, we recommend that during future updates of the ESC and SDP, consideration is given to how the design accommodates (or does not foreclose) understanding around future likely uses of the site and builds in sufficient flexibility to address uncertainties around this (**Recommendation O&E9**). This consideration may need to take into account planning permission requirements and may benefit from a clear definition of minimum cap performance requirements and cap safety systems required for the post-authorisation period.

The repository design includes a minimum 3 m thick final capping layer, in addition to a substantial thickness of profiling material above the waste. One of the functional objectives of the final capping layer is to minimise the likelihood of human and biota intrusion. LLW Repository Ltd states that the capping layer is sufficiently thick to minimise the likelihood of human intrusion and the effects of erosion (LLW Repository Ltd 2011a); the cap achieves this objective based on its physical thickness and a cobble bio-intrusion layer. All human intrusion scenarios presented in the 2011 ESC assume a 3 m thick capping layer. We accept that a 3 m thick cap is in line with other surface repository cover systems and consider it suitably optimised for the stage of development of the design, recognising that further detailed design and substantiation of the safety function of some components is still required prior to construction. Further substantiation and design work may include, for example, consideration and assessment of the performance of the cap in relation to erosion and natural disruption, or the demonstration that the cap design will minimise the potential for human and biota intrusion. We discuss the design of the final cap in Section 2.3 and we set out expectations for LLW Repository Ltd to further demonstrate optimisation and substantiate the performance of the cap in ESC-FI-001 and ESC-FI-027.

We expect LLW Repository Ltd to develop an optimised capping system. This will require further detailed work prior to construction. For example, details of how surface water run-off will be managed to minimise cap erosion will need to be developed (ESC-FI-023) and optimisation should be informed by the outputs of the engineering forward programme and the engineering performance monitoring programme (ESC-FI-026). We are confident that the engineering programmes LLW Repository Ltd has established are sufficient to achieve the required final engineering design and its substantiation prior to construction.

LLW Repository Ltd has presented a Level 3 report on 'Development of strategies for the institutional control period' (Penfold et al. 2010) that identifies and examines potential strategies for the management of the repository during the period of authorisation (for example how and when leachate and gas management systems will be closed off). We consider it important that the company continues to develop these strategies further and to incorporate them into future updates of the ESC. These strategies should include the identification of all cap functionality requirements during the period of authorisation (**Recommendation O&E10**).

Coastal erosion

LLW Repository Ltd considers that disruption of the LLWR by coastal erosion will begin from a 'few hundred to a few thousand years after the present' (LLW Repository Ltd 2011d). In support of the optimisation process, LLW Repository Ltd considered potential measures that could protect the repository from coastal disruption. The company constrained its optimisation to only consider measures that could be applied within the LLWR and has not considered measures that could be implemented by third parties such as the construction of offsite coastal defences.

Protection could be provided to the repository by constructing and maintaining sea defences at the coastline. However, any such defences would almost certainly need to be provided by (or in agreement with) a third party as the land towards the coast is not owned by LLW Repository Ltd or the NDA. The company cannot therefore rely on any such defences being constructed or maintained within their environmental safety arguments.

LLW Repository Ltd projects that the primary mechanism of disruption by coastal erosion will be by undercutting the repository at the base of the sea cliff. Because of the location of the eroding coast, the engineered features of the repository will not offer significant protection from, or impediment to, the erosion process. The 2011 ESC also presents alternative coastal erosion sequences that result from increased rates of change of sea level (LLW Repository Ltd 2011d). LLW Repository Ltd considers these alternative cases less likely to happen. For all erosion sequences, the installation of coastal defences in response to this erosion would only delay, rather than prevent, the disruption of the repository, unless the defences are maintained indefinitely, which cannot reasonably be assumed to be the case.

LLW Repository Ltd considered modifications to vault design, such as the inclusion of armouring or reinforcement, or the creation of a monolithic waste form, but considered that this would not offer significantly increased resistance to erosion because of the nature of vault disruption by undercutting. We agree with this conclusion.

Coastal defence strategies for the west coast of Cumbria as a whole are set out in the Shoreline Management Plan (Halcrow 2010a and b). The current Shoreline Management Plan covers a period of 100 years and so cannot be used to identify any shoreline management approach that might be in place throughout the whole period of authorisation and beyond. It does not include any intervention for the coast adjacent to the LLWR. We assume that the Shoreline Management Plan will be updated at regular intervals, with disruption of the LLWR potentially being covered at some point in the future, addressing any need for coastline management adjacent to the LLWR.

In ESC-RI-ASO-001 we asked LLW Repository Ltd to carry out further investigation into the potential benefits of changes to the proposed vault sequencing set out in the SDP, such that the erosion of higher hazard waste would be delayed for longer. The company considers that the only way to achieve significant gains in optimisation would be to prevent, rather than delay, disruption by coastal erosion (Paulley 2011). As already discussed, no practical optimisation measures have been identified that can be relied on to prevent disruption over the longer-term. We agree with LLW Repository Ltd's conclusion.

The GRA requires consideration of intergenerational equity and states that 'where future generations could be affected, they are afforded the same level of protection as that applied at the time of disposal without needing to take significant protective actions' (GRA paragraph 4.3.3). LLW Repository Ltd interprets this to mean that delay (rather than reduction or prevention) of doses that will happen 100s to 1000s of years in the future does not provide the optimisation benefit required to satisfy GRA Requirement R8. We agree that a delay to the start of disruption in itself confers no significant benefit.

If disruptive processes themselves, such as coastal erosion, whenever they happen, could be slowed down, this could confer a benefit to the extent that it would reduce individual annual risks. However, other consequences would also need to be taken into account, for example a cliff line with contaminated items could be in existence for a longer period of time. This is not addressed in the 2011 ESC. We recommend that in future updates to the ESC, LLW Repository Ltd considers the potential for the provision of passive engineered features to mitigate and slow disruptive processes, thus also serving to reduce individual annual risk (**Recommendation O&E11**).

Using the coastal erosion sequence set out in LLW Repository Ltd (2011d), LLW Repository Ltd has investigated potential optimisation measures that could be instigated during the period of authorisation to minimise radiological impacts associated with coastal erosion. LLW Repository Ltd considers that the installation of engineered provisions such as coastal defences at the site would not protect the facility in the long-term from coastal erosion and LLW Repository Ltd does not take credit for these provisions in the 2011 ESC. The GRA seeks demonstration of performance assuming no human intervention, and so the ESC should not rely on the use of engineered provisions that require maintenance such as coastal defences. However, this does not preclude an assessment of the effectiveness of engineered provisions so long as the ESC does not rely on them. From the perspective of achieving risks that are ALARA, LLW Repository Ltd considers that there is evidence from the results of its environmental safety assessments to indicate that these measures (that would imply a long-term requirement for maintenance and re-building) would not be proportionate to the risk reduction achieved. Any decision on the installation of engineered coastal defences would involve a much wider range of considerations relevant at the time. The level of risk reduction may not be the most important factor in reaching a decision.

The 2011 ESC presents a repository design that does not preclude the provision of coastal defences by future generations, either to protect the LLWR specifically, or as part of wider plans for coastal management in Cumbria (LLW Repository Ltd 2011b). During the life of the repository, the nature and rate of coastal erosion will become clearer; this, together with progressive reviews of environmental safety and socio-economic assessment criteria, will allow decisions on protecting the repository from coastal erosion to be taken or changed at any time. Taking account of current site understanding and known uncertainties, we consider that the 2011 ESC has adequately identified potential optimisation measures that could mitigate disruption and has demonstrated that LLW Repository Ltd's proposal not to adopt these measures meets regulatory requirements.

Because the provision of coastal defences would confer no benefit that can be claimed in the ESC, we consider that the assumption made in the 2011 ESC that no coastal defences are provided is appropriate. Based on the information presented in the 2011 ESC, we accept LLW Repository Ltd's argument that any active management beyond 300 years after the end of final waste emplacement (other than the measure of retrieving waste from the LLWR), would offer only a small radiological protection benefit. In any case, we note in the GRA that, 'Because of the major social changes that may take place over long periods of time, it is unlikely that the environment agencies would accept a claim for active institutional control lasting longer than 300 years after the end of waste emplacement' (GRA paragraph 6.3.8).

We accept the difficulty of identifying engineered provisions that, without human intervention, would resist threats from coastal erosion and inundation in the long-term. Given this, the 2011 ESC ultimately rests on the acceptability of the proposition that, with near certainty, existing and potential future waste disposals, subject only to radioactive decay, will return to the environment as a result of coastal erosion.

In the 2011 ESC and further responses provided at our request, LLW Repository Ltd showed that the radiological consequences of LLWR disruption by coastal erosion are consistent with environmental safety criteria (Environment Agency 2015e).

2.2.3. Management of future waste disposals

LLW Repository Ltd sought to optimise the management of future waste disposals by considering its future site operations, management controls and engineering designs. Optimising the operational management of the LLWR includes controls covering the acceptance of waste for disposal, how this waste is conditioned and packaged, and the way in which it is emplaced in the facility. LLW Repository Ltd has also considered whether its approach to the management of waste disposals could foreclose the possibility of retrieving waste, if required.

WAC and operational management

LLW Repository Ltd refined the LLWR WAC based on the results of the 2011 ESC and subsequent work to make sure that disposal practices remained optimised and aligned with the current ESC (LLW Repository Ltd 2011f, 2013b and 2014). Where appropriate, LLW Repository Ltd has developed operational measures such as emplacement strategies and radiological capacity assessment to make sure that radiation doses and risks, both now and in the future, are as low as reasonably achievable (ALARA). In our Safety Case Management report (Environment Agency 2015b), we present the outcome of our review of the WAC against both the information presented in the 2011 ESC (LLW Repository Ltd 2011f) and assessments carried out since the submission of the 2011 ESC (LLW Repository Ltd 2013b). We consider that LLW Repository Ltd's proposed operational measures are appropriately optimised.

There remains significant uncertainty in the timing, composition and total amount of future waste disposals. We consider the WAC and capacity controls are sufficiently flexible to accommodate this uncertainty and to ensure disposals remain optimised. Continued demonstration of optimisation of the LLWR in its entirety will need to take into account developing understanding of the waste inventory, emplacement strategies within the vaults, vault design and size and capping. LLW Repository Ltd has identified triggers associated with waste disposal types and quantities that will prompt assessment for consistency with the WAC and ESC in accordance with the WAC, procedures and other quality systems (LLW Repository Ltd 2011f).

The GRA does not require the optimisation of design and management approaches in relation to non-radiological discharges. Instead non-radiological impacts must be a consideration in the optimisation of design and management approaches for radiological discharges and they must be adequately limited. The LLWR design is intended to keep the waste in a relatively dry state for several 100 years until significant failures in the cap begin to occur. This approach will significantly limit leaching and biodegradation (and hence releases) before significant cap performance degradation, unlike many conventional landfill designs. But, the non-radiological hazard in the vaults will largely persist for several 100 years until water comes into contact with the waste following cap degradation. We consider that, before significant degradation of the engineered cap, the vault design provides a level of protection consistent with that required by the national standards at the time of disposal of waste that present a non-radiological but not a radiological hazard (GRA Principle 3). Prior to and following significant degradation of the cap, LLW Repository Ltd has assessed the resulting impacts and has demonstrated to us that they are acceptable and consistent with standards and guidance (Environment Agency 2015e). We consider that non-radiological impacts have been adequately limited and considered alongside radiological optimisation.

We assessed the WAC presented with the 2011 ESC (LLW Repository Ltd 2011f), together with revised WAC that formed part of the LLW Repository Ltd application for a varied environmental permit (LLW Repository Ltd 2013b). The WAC presented as part of the permit variation application include further optimisation measures identified after issue of the 2011 ESC including revised emplacement strategies and restrictions on the disposal of discrete items; these changes are described in the Developments Document (LLW Repository Ltd 2013b). Where possible, LLW Repository Ltd has already implemented these optimisation measures under the existing environmental permit (LLW Repository Ltd 2014). Some of the measures, however, can only be implemented under a varied permit.

As part of the optimisation process, the revised WAC forming part of the permit variation application introduced measures to limit the magnitude of potential container settlement by restricting disposal of waste liable to settlement, requiring certain waste packing approaches and encouraging the potential for settlement to be characterised (LLW Repository Ltd 2013b). We welcome these measures that form part of a wider range of measures needed to minimise long-term cap settlement. We discuss the nature and extent of future work we consider necessary to provide an optimised container design and minimise settlement in ESC-FI-025 and ESC-FI-027.

The current WAC do not allow the disposal of any complexants to meet requirements in the current permit which are there due of their potentially adverse effect on contaminant solubility and mobility in the groundwater environment. Since the submission of the 2011 ESC, LLW Repository Ltd has completed substantial investigations into the environmental consequences of complexants and as a result has proposed to allow the controlled disposal of complexants, limiting some complexants (for example aminopolycarboxylic acids) and preventing the bulk disposal of any complexants. We assess the suitability of the WAC to achieve the ESC objectives elsewhere (Environment Agency 2015b and e). The resulting WAC assessment and control measures for the disposal of complexants are considered optimal.

We consider that both the changes to the WAC that have already been implemented and those that LLW Repository Ltd proposes to implement after the environmental permit has been varied are consistent with the optimisation objectives set out in the 2011 ESC and the GRA.

Optimisation of the container and grouted waste form

In the 2011 ESC, LLW Repository Ltd has presented investigations into the nature of the waste form and its associated packaging and management (LLW Repository Ltd 2011g). LLW Repository Ltd state, in the 2011 ESC, that it considers the current grouted waste form to be optimised, providing several environmental safety, operational and efficiency benefits, namely the containment and isolation of waste and the minimisation of waste settlement (LLW Repository Ltd 2011a and g).

During our review we raised questions about the containers in Vault 8, some of which we and LLW Repository Ltd observed to be in poorer condition than anticipated (ESC-RI-INF-005). Matters of particular note include (Environment Agency 2015j):

- observed corrosion and degradation of some containers
- the presence of significant ullage at the top of some containers in Vault 8

We note that the 2011 ESC was not able to take account of these observations, which were made following its submission. In response, LLW Repository Ltd undertook a substantial programme of work to further investigate the condition of existing containers on site and the implications of any degradation (Jefferies 2012, 2013a, Westlakes Engineering 2012a, b). LLW Repository Ltd has identified (and instigated where possible) ways of improving the waste packaging, grout infill and container sealing for future container disposals (LLW Repository Ltd 2013b). The investigation has identified design modifications that could improve container integrity. These will be addressed over a longer timescale as part of a comprehensive container optimisation programme alongside the engineering forward programme (Shaw 2013).

The objective of the container optimisation programme is to investigate potential improvements to the container that could reduce container degradation and improve containment before the placement of final cap, along with other potential improvements, such as the reduction of raw material use in their construction. The outcome of the container optimisation programme will also inform the ongoing optimisation of the vault restoration sequence and cap engineering and vice versa. For example, should a decision be made to cap waste quicker in the future, the container will not be required to be engineered to withstand exposure to the elements for as long as if waste remains exposed for longer.

In addition, LLW Repository Ltd will implement proportionate measures to improve the performance of the containers currently disposed or stored on site where practicable. The measures may include the removal of vegetation from the containers, the removal of water from the ullage space, plugging of open grout ports and preventing water accumulation on the containers, as consistent with BAT. In ESC-FI-025 we set out our expectations for the protection of waste prior to capping.

In the 2011 ESC, LLW Repository Ltd assumes that the waste containers will maintain their integrity over an extended period after the placement of the final cap and will maintain the integrity of the grouted waste form for a period of between several 100 years and 1000 years in the anaerobic conditions that are predicted to develop after capping (LLW Repository Ltd 2011g). During our review we queried the evidence supporting this assumption as, following container degradation, vertical (and horizontal) loading will be transferred to the grouted waste form. Settlement of this waste will depend on the integrity and the void filling capacity of the waste. This settlement potential is likely to be influenced in part by the grout to waste ratio, which we note is low in some containers (ESC-TQ-INF-006). We consider that the waste is unlikely to always act as a stable monolith, preventing waste and container settlement. Therefore, LLW Repository Ltd should ensure that the cap settlement assessments included in its forward engineering programme (and requested by us in ESC-FI-001) takes account of the uncertainties in the behaviour of the grouted waste form after loss of container integrity. For example, LLW Repository Ltd has not investigated the timing or sequence of container failures and the influence of this on cap settlement. Neither has the company taken account of the potential for accelerated container failure resulting from processes that may happen before final capping, such as degradation of the containers themselves and voidage created within the containers by grout settlement or degradation. However, we note that LLW Repository Ltd indicates its approach to assessing settlement potential is overall conservative, in that it only takes credit for the volume occupied by the materials and not the structural integrity of the wasteform and containers. We expect LLW Repository Ltd to develop a programme to investigate the possible causes and effects of loss of container structural integrity on the timing and significance of cap settlement (ESC-FI-027).

We conclude that LLW Repository Ltd has not yet fully optimised the current container design and management approach for the protection of waste prior to capping. However, the company has assessed the observed degradation of containers currently on site and has put in place a work programme to address the outstanding issues and their possible impacts on cap settlement (Shaw

2013). We expect the necessary improvements to be met by a combination of changes to container design, changes in waste acceptance and consignor practice, grouting process, control of stack heights and restrictions on container exposure prior to capping or other forms of protection being put in place. We believe that this work will allow the company to optimise the container design and their protection prior to capping and to optimise potential issues associated with cap settlement. The outcome of this work may influence the maximum stack height that can safely be achieved in the vaults and therefore the resulting volumetric waste capacity of the repository.

Since the submission of the 2011 ESC, LLW Repository Ltd has changed the WAC and has worked with consignors to help minimise settlement potential. The company has also sought the increased availability of packaged waste photographic records. These positive measures will assist in providing an optimised waste form. In future updates of the ESC we expect to see how waste records and waste packing photographs have been used to inform understanding of the waste, its changing composition and in particular its settlement potential and therefore optimisation.

We consider that LLW Repository Ltd now has a better understanding of waste container issues and will be able to incorporate this understanding into the repository design and ESC. In particular, we are satisfied that:

- LLW Repository Ltd has appropriately investigated the mechanisms causing the observed container degradation and the voidage created within containers by grout settlement. The company has identified and will implement suitable control and mitigation measures.
- LLW Repository Ltd will in future update the ESC, WAC and operational procedures to take account of the observed container degradation and grout settlement within containers.
- LLW Repository Ltd has identified appropriate measures to minimise the risk that future site operations do not lead to continuing issues with container degradation and grout settlement. These measures will be taken into account in the future optimisation of the container design, protection of the waste and restoration sequence.

Regarding further work on the optimisation of the container, grouting and settlement, we set out expectations in ESC-FI-001, ESC-FI-025 and ESC-FI-027. We consider that this work, alongside LLW Repository Ltd's current forward engineering programme and work on container optimisation will be sufficient to establish a fully optimised design. We expect settlement issues to be fully addressed before the commencement of the capping of Vault 8. We also expect good progress towards developing a fully optimised means of containing the waste before capping.

Emplacement strategies

The 2011 ESC identifies several potential emplacement strategies that could be used to limit effects resulting from various waste properties (LLW Repository Ltd 2011f). In pursuit of an optimised approach, LLW Repository Ltd further explored these emplacement strategies during the period of our review, setting out the results in the Developments Document (LLW Repository Ltd 2013b). These emplacement strategies provide further reassurance and improved environmental safety.

LLW Repository Ltd has developed emplacement strategies to:

- avoid co-location of waste containing particular radionuclides with specific activities above certain values
- make sure that containers with particular radionuclides with high specific activities are not emplaced within 5 m of the surface of the engineered cap

We consider that these strategies will provide a practical and effective way of optimising container emplacement taking into account the radiological properties of the waste they contain. As discussed in our Safety Case Management report (Environment Agency 2015b), we are satisfied that LLW Repository Ltd has put in place plans to achieve effective container emplacement and we expect LLW Repository Ltd to implement these plans.

Based on the 2011 ESC and in response to the outcome of the container condition investigations LLW Repository Ltd identified a number of emplacement strategies that will minimise settlement and compression (or expansion and heave) of the waste as a result of the amount of void present in the packaged waste, the loading applied or the waste types present, as well as minimising the generation of free liquids from absorbed liquids. These include:

- limiting the total voidage that could be present within a single container stack to mitigate settlement
- limiting the waste metal content within a single stack to mitigate expansion and heave
- limiting the maximum loading within a single stack
- excluding absorbed liquids from stack locations with high loadings to prevent the generation of free liquid

We consider that these measures are capable of minimising potential waste settlement. However, we sought clarification of LLW Repository Ltd's proposals for implementing these emplacement strategies both for the waste containers currently stored or disposed in Vault 8 and for future disposals to Vault 8 in ESC-TQ-ASO-001. In response, LLW Repository Ltd identified 3 categories of waste of relevance to Vault 8:

- **Category 1**: Waste currently disposed of or stored (waste currently disposed of or stacked to a height equivalent to that of 4 half-height ISO freight containers and waste stored in higher positions to a height equivalent to that of 6 half-height ISO freight containers)
- **Category 2:** Waste that will be disposed in the remaining space permitted for disposal (stacked to a height equivalent to that of 4 half-height ISO freight containers)
- **Category 3**: Waste that might be stacked above the waste in the first 2 categories

LLW Repository Ltd does not plan to apply these emplacement strategies to Category 1 waste. However, LLW Repository Ltd plans to assess the extent to which the emplacement of these waste is already compliant with the strategies, with the aim of optimising the emplacement of future disposals to Vault 8. We will require a BAT case to be produced before the beginning of higher stacking (ESC-FI-001).

This has a bearing on the maximum safe stack height. LLW Repository Ltd is yet to produce procedures to implement this strategy, which would form part of the beginning of the Vault 8 restoration plan (the Phase 1 Implementation plan). For the strategy to be effective there must be links to the collection of waste information on total potential voidage, the evolving engineering design and the height of existing stacks and total potential voidage within them. This aspect of the emplacement strategy, along with relevant procedures, needs to be implemented before the movement and importation of containers in Vaults 8 and 9. At present LLW Repository Ltd has implemented an approach which does not allow the emplacement of waste into Vault 8 without the agreement of the ESC Manager, thus ensuring that the waste is emplaced to take account of the requirements of the emplacement strategy.

The BAT study may need to consider the following options: leaving the Vault 8 waste containers where they are; moving the Vault 8 waste containers and locating them according to the emplacement strategies; installing specialist engineered or settlement mitigation features; and retrieving containers to undertake a range of alternative reworking options. The resulting BAT solution may result in a change in maximum stack height that can safely be achieved and the physical capacity of Vault 8 for waste disposal. LLW Repository Ltd has already instigated a programme of work to determine the maximum safe stack height for Vaults 8 and 9, and the future vaults, before placement of a cap (Jefferies 2012, 2013a). We set out our requirements for demonstrating that the chosen stack height can maintain the necessary cap performance in ESC-FI-001 and ESC-FI-027.

With regard to the total future predicted volumetric capacity of the LLWR, the company has made it clear that it can modify the operational and restoration design set out in the 2011 ESC to take account of changes in the total quantity of waste as well as required restrictions in the maximum container stack height. There remains some uncertainty in the maximum stack height that can be achieved both for Vault 8 and for future vaults. This uncertainty is associated with the significance and confidence in assessed container settlement potential. We discuss this further in Section 2.3.11 of this report and in Environment Agency (2015j). In ESC-FI-001 we outline our expectations for LLW Repository Ltd to prepare and implement a programme to optimise stack heights. If the maximum stack heights necessary to provide the single dome restoration design are not achievable, then we will require LLW Repository Ltd to review whether the repository restoration shape and sequence remains optimal, for example considering the implications of the need to import additional profiling materials.

The emplacement strategies presented in the Developments Document (LLW Repository Ltd 2013b) include a number of container emplacement strategies aligned to the outputs of the 2011 ESC. We are satisfied that these strategies are appropriate.

Optimisation of the construction and restoration approach

In the 2011 ESC, LLW Repository Ltd presents a restoration sequence in which the final cap is constructed in successive strips. This entails the construction of a strip of the final cap over a disposal vault that has been filled and extending over the adjacent interim trench cap (LLW Repository Ltd 2011b). This restoration sequence has been derived taking into account the timing and quantity of waste inputs identified in the United Kingdom Radioactive Waste Inventory (UKRWI) (NDA 2011).

We consider that a restoration sequence, its timing and its flexibility needs to take into account uncertainties in the waste footprint, rates of waste input, the ongoing performance of the existing interim trench cap, the condition of uncapped exposed waste and its assessed lifetime before requiring protection, operational considerations and external factors such as the availability of restoration materials. Restoration should aim to achieve BAT through the minimisation of discharges and environmental impacts resulting from the disposed waste. The optimisation of the restoration sequence and timing is essential to meet the performance assumptions used in the 2011 ESC.

Although we accept that LLW Repository Ltd has presented an optimised restoration sequence in the 2011 ESC based on the information available at the time of writing, we expect this to change and adapt as further information becomes available and as it is further optimised, as a minimum at each major ESC update. For example, in ESC-FI-025 we outline expectations for the company to consider the sequencing and frequency of vault capping (and vault size) to provide sufficient protection to waste containers before they degrade as a result of exposure.

LLW Repository Ltd's currently defined restoration sequence relies on the grouted container to provide containment of waste before construction of a final cap. For some of the later vaults, it is assumed that some of the containers could be exposed for periods of up to 25 years before placement of a final cap. The consequences of prolonged exposure of containers were explored as part of the company's container investigation programme (Jefferies 2012, 2013a). The programme identified a range of degradation processes that could affect container and waste integrity before placement of a final cap. One output was the need either to minimise the period of exposure of containers before capping or to optimise the containers to minimise degradation, or a combination of both.

We consider that, in determining an acceptable period of container exposure prior to capping, LLW Repository Ltd should take into account the container design life, in situ container condition observations and any container specific research, with a presumption of early protection of the waste. As mentioned above, we outline our expectations for this work in ESC-FI-025. We expect LLW Repository Ltd to complete a programme of work to substantiate a maximum container exposure period, taking into account any improved container design and measures put in place to protect containers before capping.

LLW Repository Ltd provided Vault 8 monitoring data confirming that the existing containers effectively act as ‘mini disposal cells’ and offer substantial protection against the generation of contaminated leachate before the placement of the engineered cap. Although the containers have visibly degraded, they have retained much of their containment functionality with very low levels of radioactivity being detected in the vault leachate (Champion 2012). We accept that discharges resulting from the ISO freight containers are low, but expect further optimisation of the container design and vault restoration sequence to further minimise discharges during the operational period (ESC-FI-025). We expect a fully optimised container design and restoration sequence will be able to provide sufficient containment of waste prior to capping.

During our review we raised an RI (ESC-RI-ASO-002) regarding the possibility of covering the waste containers or providing a temporary roof over the vaults to help protect the containers from water damage and ingress, and to minimise corrosion. In response to the RI, LLW Repository Ltd noted that there were opportunities to further optimise the current waste form from the perspective of long-term environmental safety performance, but stated that the grout infill in the containers provides a primary barrier to minimise water contact with the waste materials (Egan 2011b). In addition, the half-height ISO freight container itself and the capping grout (added primarily for load distribution and stack stability reasons), also serve as barriers to water ingress. We accept these arguments, but note that we are unsure of the extent of the performance benefits claimed for the capping grout (Environment Agency 2015j).

In ESC-RI-ASO-002 we asked LLW Repository Ltd why the 2011 ESC does not explicitly explain why covering the vault with a temporary tent or roof during the operational period, or otherwise protecting the disposed or stored waste against water, would not be optimal. In response, LLW Repository Ltd stated that the construction of a roof over the vaults is effectively precluded by the vault design, which entails the emplacement of large-sized containers on an extensive vault platform to make best use of available space. A suitable roof structure across the span of the vaults could not be engineered without major effects on emplacement operations and the efficient use of space. We agree that the current vault design is not conducive to the installation of a temporary weatherproof roof and would not currently represent BAT. We accept that there are severe obstacles to installing a large scale roofing system for the vaults. However, we expect LLW Repository Ltd to keep this option open for consideration in the future.

Other options to protect waste prior to capping may include container-scale or small-scale temporary or interim covers. These options may restrict operations, for example by restricting the movement and stacking of containers. However, options should be considered in the future and the detriments balanced with the potential benefits of improved container integrity and reduced discharges. Further options could include the placement of an interim cover material or partial cap while the vault is being filled (LLW Repository Ltd 2011a). In ESC-FI-025 we require LLW Repository Ltd to re-consider these and other options to protect the waste prior to final capping, taking into account further container design optimisation and further optimisation of the restoration sequence.

We conclude that the restoration sequence has been optimised to the extent possible at this point in time. However, further work is required, as identified by LLW Repository Ltd and us, to re-consider container design and other ways of protecting the waste up to the point of final capping (ESC-FI-025).

Complexity of engineering and repository design

An important element of optimisation is the development of an engineered repository that can be constructed to achieve the stated performance at both the level of a single engineered system and at a repository scale. Individual components, the whole repository and the construction and restoration sequence should all be considered in the optimisation process. Given the relatively conceptual nature of the proposed engineered system at its present stage of development and the need for further, more detailed design prior to construction, we expect the design to be subject to further optimisation before construction.

In particular we consider that both the design of the capping layers and the interface between restoration strips may be complex and could potentially benefit from further optimisation as further, more detailed design work is carried out. We are aware that LLW Repository Ltd is progressing more detailed design work in these areas and accept that this is part of the normal design development and substantiation process. However, in ESC-FI-027 we ask LLW Repository Ltd to consider further optimisation of the discrete cap functional layers within the design justification process taking account of the design complexity and ease of construction.

Hydrogeological model support to the engineering performance assessment

Optimisation studies relating to the engineering design of the LLWR with respect to both operational and post-closure safety are described in Paulley and Egan (2011). To support the optimisation decision-making process, LLW Repository Ltd carried out a series of variant hydrogeological calculations to assess the performance of various components of the engineering design (for example, looking at the vertical saturation profile and flow rates through the cap) (Hartley et al. 2011). This study was based on the 'Vaults Single Option design'[7] and was not included as part of the 2011 ESC submission. The 'Vaults Single Option design' differs significantly from the current reference design (RDA) for post-closure engineering in a number of respects, for example, the former included a double dome (gull wing) cap instead of a single dome, a deeper cut-off wall, an alternative future vault layout and vertical drainage instead of a horizontal basal drainage layer. The company used the model output to underpin the optimisation process and performance assessment.

Using the 'Vaults Single Option design', Hartley et al. (2011) modelled and assessed a substantial number of design variants for each of the main components of the engineering design, including:

- higher stacking of vault waste
- depth and performance of cut-off wall
- performance of the final capping system

We consider this good practice, but note that the modelling did not consider variants that incorporated significant elements of the 2011 ESC design, for example, the single dome cap and horizontal basal drainage layer. Furthermore the hydrogeological model has subsequently been updated. Although we consider the hydrogeological modelling against the 2011 ESC design to be adequate, we would like to see modelling of variants repeated against the full ESC design in the future.

We note that much of the learning from Hartley et al. (2011) is not discussed in the 2011 ESC and we are unclear as to the extent that it has been used to inform the engineering optimisation process or engineering design validation process. However, we consider that the modelling reported by Hartley et al. (2011) provided a suitable starting point for assessment of the hydrogeological performance of design variants that could have been updated and used to further inform the 2011 ESC. For example:

- Full and localised cap failure are modelled, the latter being associated with failure in the eastern end of the trough in the gull wing cap. There is a significant probability for near-surface release in the case of early cap failure (infiltration through cap at 50% or 100% of HER, variants for clogging of the vertical drain are also considered). We consider that assessment of similar failure scenarios would be valuable to underpin the engineering design optimisation process and to inform the engineering performance assessment. We outline our expectations for a wider cap failure assessment taking account of the impact of the container condition survey in ESC-FI-001 and ESC-FI-027 and request consideration of use of a wider approach to engineering performance assessment in ESC-FI-026.
- One scenario considers an alternative vault design of stepped vault bases and 1 m internal vault walls, similar to the current reference design. A variant to this scenario considers a decreased horizontal conductivity of the vault waste (10^{-6} m s^{-1} compared with the central simulation assumption of 10^{-2} m s^{-1}). This variant scenario was modelled to allow the assessment of the implications of the reduced effectiveness of the leachate drainage system and could be used to support the development of a leachate management strategy and design. We request further investigations into leachate failure scenarios as part of ESC-FI-023.
- A large number of variants consider the effects of clogging of the vertical drainage system that formed part of the Vaults Single Option design. However, there is no assessment of the effects of clogging of the horizontal basal drainage layer that underlies the future vaults in the 2011 ESC reference design. Such an assessment would have been useful in demonstrating the long-term performance of the basal drainage system. We request further investigations into the long-term behaviour of the basal drainage layer in ESC-FI-023.

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[7] The 'Vaults Single Option design' was the output of an optimisation exercise carried out which evaluated and developed a single option for the future development of the LLWR within the context of the national LLW Policy (Williams and Proctor 2007).

- Higher stacking appears to increase the potential for near-surface release associated with overtopping scenarios or other situations in the repository that involve high infiltration through the cap in conjunction with limited release of leachate through the basal drainage layer. As part of ESC-FI-023 on investigations into the leachate management strategy, we require demonstration that the chosen stacking arrangement and associated leachate drainage infrastructure does not compromise the functionality of the leachate collection system.

As the design optimisation process continues, we expect LLW Repository Ltd to substantiate the design and projected performance of the components of the engineered barrier system with reference to an appropriate set of variant hydrogeological calculations (ESC-FI-023, ESC-FI-024, ESC-FI-026 and ESC-FI-027).

In our review of the 2002 PCSC, we noted that BNFL should justify or revise the screening-out of diffusion through the cut-off wall (IAF GEO_024.2; Environment Agency 2015h). This exercise does not appear to have been carried out in the 2011 ESC. We therefore recommend that LLW Repository Ltd investigates the implications of diffusive flow through the engineered barriers, or substantiates why these flows are insignificant compared with advective fluxes (**Recommendation O&E12**).

2.2.4. Optimisation of engineered systems

Most of the components of the LLWR engineered systems have evolved from the designs presented in the 2002 PCSC. The resulting engineering design stems from a comprehensive optimisation programme that examined the constraints on the previous design and the need to provide optimised disposal. The outputs from the optimisation programme have informed the SDP and have supported the construction of Vault 9. LLW Repository Ltd has subsequently explored variants from this baseline as part of a comprehensive re-evaluation of design options and their implications.

LLW Repository Ltd has sought to identify engineering options that provide a clear benefit in terms of establishing confidence in the environmental safety performance of the LLWR. LLW Repository Ltd has then assessed each option to determine if it is materially affected by wider considerations. This process has sought to recognise contributions to optimisation from both a broad strategic perspective and a more detailed design perspective (LLW Repository Ltd 2011a). We have reviewed LLW Repository Ltd's process for considering engineering options and have concluded that the scope and approach are appropriate.

We welcome the inclusion of hydraulic performance information in the optimisation process and the increased emphasis on establishing confidence in environmental safety performance. However, the hydraulic performance assessment was based on an old engineering design and omitted significant components of the current design, such as the single dome cap and basal drainage layer. Although most components of the engineered system use conventional and proven designs and materials, assessment of performance (especially longer-term performance) is particularly important for the more novel aspects of the design (for example, the multi-layer cap and the basal drainage layer). In future optimisation decision making, we expect to see a more effective linkage between hydraulic performance and design objectives (**Recommendation O&E13**).

In order to improve the clarity of the engineering optimisation process, as well as further supporting the engineering design justification process, we recommend that future updates of the ESC would benefit from clear documentation that outlines the processes LLW Repository Ltd has used to determine the engineering design, which provide details of baseline assumptions, inputs to the decision making process and substantiation of chosen components. It might include, for example, engineering objectives and functional specifications (**Recommendation O&E14**).

As noted earlier, we consider that some aspects of the engineering design presented in the 2011 ESC for the future vaults and for closure of the repository are relatively conceptual in nature. Some aspects are also relatively novel, or have not been used widely elsewhere in the form LLW Repository Ltd proposes, for example, aspects of the cap design, basal drainage layer and leachate collection system. In addition, the overall engineering design is expected to function over a very long period compared with conventional engineered structures. We therefore expect there to be further opportunities to optimise the engineering design as it is developed up to the point of implementation, which may result in a number of changes. However, as LLW Repository Ltd proposes to operate the facility for more than a further 100 years, it is unrealistic to expect the engineering design presented in the 2011 ESC to be complete in all respects. The GRA requires the ongoing optimisation of the disposal facility and its operation, taking account of technological improvements in the area and learning from experience.

We discuss the optimisation of individual aspects of the engineering design in the following sub-sections.

Optimisation of the engineered cap

The cap designs presented in both the 2002 PCSC (BNFL 2002b, 2002c) and the 2011 ESC (LLW Repository Ltd 2011b) are similar, comprising a single dome cap and multi barrier system. An alternative restoration cap design comprising double domes ('gull wing' design) was adopted in the period between the 2 environmental safety cases (Williams and Proctor 2007), but this was rejected after engineering optimisation studies (Egan 2011b). The design of the layers within the final engineered cap has not changed greatly between the 2002 ESCs and the 2011 ESC, the most significant change being to the restoration shape with only limited changes to the functional cap layers.

We note that the change from a double dome to a single dome cap design offers advantages, by offering a simpler design, removing potential issues with valley erosion and water management between the 2 domes and minimising the potential for cap settlement and human intrusion. We therefore consider the design to be adequately optimised. However, we note that the double dome design did offer some advantages, such as the potential to allow the accelerated final capping of the trenches, ease of construction and the use of less imported materials to create the required profile. As with all aspects of optimisation we expect LLW Repository Ltd to undertake ongoing reviews of the chosen design and to re-evaluate and reconsider options. This should include re-evaluation of the cap design as part of the ongoing optimisation of the interim trench cap and as part of the Phase 1 Implementation Programme. We outline our expectations in ESC-FI-001 and ESC-FI-025. We recommend that the next major review of the ESC specifically includes a review of the optimisation of the cap design carried out since the submission of the 2011 ESC (see Recommendation O&E2).

The cap performance objectives presented in the engineering design section of the 2011 ESC (LLW Repository Ltd 2011b) are described qualitatively and in some cases quantitatively. As the cap design is developed we expect the performance objectives for the cap drainage layer to be further specified, considering the significance of the potential effects of clogging, chemical precipitation and reactions, and bio-fouling. More generally, we expect that before cap construction LLW Repository Ltd should set out suitable performance objectives for the engineered cap with demonstration, as far as possible, that the design can meet them. Because settlement represents a significant potential cap failure mechanism there is a need to identify appropriate measures to mitigate the effects and to protect the caps performance. LLW Repository Ltd uses the cap thickness as the main way of achieving these results. Although a generally conservative approach has been taken and we consider the approach adequate, it is nonetheless relatively simplistic. The approach may benefit from further more detailed work to identify other aspects of the cap design that contribute to mitigation against cap settlement. In ESC-FI-026 we ask LLW Repository Ltd to specify performance objectives for each component of the overall capping system, supported by suitable evidence, to facilitate and inform further optimisation work and the design development and substantiation process.

LLW Repository Ltd does not present evidence in the 2011 ESC that the design of individual layers in the final engineered cap has been optimised, as the company considers that this work was largely completed in previous studies. However, we understand that this work is available, for example references describing the previous optimisation work on the final engineered cap were made available to workshop attendees during the optimisation workshops.

While we consider that LLW Repository Ltd has optimised the capping concept as a whole, an improved understanding of the environmental safety functions and performance objectives of each layer of the cap may offer significant advantages. This may facilitate better design, potentially allowing the company to establish a more integrated overview of the cap design requirements and how they can be met, thus enabling individual layers to be refined or removed to provide a fully optimised cap.

LLW Repository Ltd's single dome design includes several slope elements with gradients greater than 10%. While these steeper slopes are demonstrated to be geotechnically stable, they will be subject to increased erosion over the extended life of the repository when compared to shallower slopes. We consider that slopes with angles greater than around 10% would benefit from further consideration of optimisation to take account of potential long-term erosion. As part of the ongoing engineering design and optimisation process we recommend that LLW Repository Ltd considers the feasibility of reducing the angle of the steepest cap slopes or to consider measures to mitigate long-term erosion (**Recommendation O&E15**).

Optimisation of the vault basal lining system

Future vaults will include a composite lining system designed to provide effective long-term containment, appropriate structural integrity and physical robustness. The 2011 ESC takes account of changes in the performance of the low permeability elements of the basal lining system as it degrades over a period of several 100s of years. The hydraulic conductivity of the basal lining system will eventually become similar to that of the surrounding clay geology.

We consider that the future vault basal lining system is capable of achieving a performance equivalent to the regulatory expectations for the lining of a non-hazardous landfill (Council Directive 1999/31/E 1999), while also achieving an acceptable radiological protection performance. We expect LLW Repository Ltd to continue to further optimise the basal lining system during the design development and substantiation process.

The 1 m side liner lip feature differs from hazardous and non-hazardous landfill designs, to facilitate overtopping and minimise potential for near-surface leachate releases. LLW Repository Ltd provides evidence that this design has been optimised. We accept the radiological protection and optimisation arguments used to inform this design.

Optimisation of the drainage systems (leachate collection and basal drainage)

The 2011 ESC presented 4 optimisation objectives that underlie the company's engineering strategy for vault leachate management throughout the lifetime of the repository (LLW Repository Ltd 2011a):

- containing and isolating the waste for as long as possible
- keeping the waste in a unsaturated state for as long as possible by maintaining very low leachate levels within the vaults
- when cap degradation occurs, minimising contact time between waste and leachate before dispersion
- diverting overtopping leachate from near-surface receptors

For these objectives to be met, leachate needs to behave as described in the 2011 ESC for a period of several 100 to several 1000 years. An optimised design needs to take account of both shorter and longer-term leachate management objectives to ensure that it performs acceptably during both the period of authorisation and afterwards. We accept that, subject to further detailed design development and substantiation, the 2011 ESC leachate management strategy provides an appropriate standard of radiological protection for the whole life of the LLWR.

However, the 2011 ESC did not include an holistic leachate management strategy describing fully how leachate will be managed together with supporting engineering performance information. This demonstration can reasonably be provided prior to further construction. Additionally, we consider that the long-term performance of the leachate drainage system may require further investigation to support the assumptions used in the 2011 ESC. Our requirements for developing the optimised leachate management strategy further are set out in ESC-FI-023.

The ‘vertical drain’[8] concept from the 2002 PCSC (BNFL 2002b, 2002c) is no longer used to provide contingency against the possibility of near-surface releases. LLW Repository Ltd's current design intent is to divert leachate, which will be generated increasingly as the engineered cap degrades, into the shallow geology adjacent to and below each future vault. To achieve this, LLW Repository Ltd proposes to install a passive basal drainage layer underneath future vaults and to utilise in-situ geological materials. This drainage layer is designed to function after failure of the engineered cap to mitigate the overtopping of leachate into the near-surface environment. This design is discussed further in Section 2.3.11 of this report.

The vertical drain concept presented in the 2002 PCSC was supported by an extensive research programme to investigate its long-term performance and potential failure mechanisms. The 2011 ESC presents a different drainage system design and has used a combination of elicitation, geological characterisation and modelling to assess its future performance and to demonstrate that the vertical drains are no longer required. LLW Repository Ltd will use a combination of in situ and engineered granular materials to provide the required drainage capacity under the future vaults within the passive basal drainage layer (LLW Repository Ltd 2011b).

We accept LLW Repository Ltd's arguments that an extensive basal drainage layer is less vulnerable to degradation of performance over time (for example, as a result of clogging) than a vertical drainage system. Overall, we consider that the basal drainage layer represents part of an optimised engineering design, capable of mitigation against overtopping and the eventual degradation of the cap. However, we note some lack of clarity within the 2011 ESC of the defined environmental safety role of the basal drainage layer after the end of the period of authorisation has made it difficult for us to assess the proposed system. This is later clarified in Shevelan (2012a). In addition, the 2011 ESC did not provide detailed clear information about the vault, side liner and basal drainage layer designs (in-situ or engineered) to demonstrate that these designs have been fully optimised in all details. We will require the leachate management strategy produced in response to ESC-FI-023 to address these further expectations during the detailed design and justification process and before construction of future vaults.

LLW Repository Ltd states that the provision of a vault basal drainage layer using either in situ natural granular material or supplemented with engineering materials is specifically for reassurance purposes, to provide additional drainage capacity above that provided by the adjacent in-situ granular geologies. To optimise the basal drainage system for each vault, we recommend that the functional requirements of this system (drainage capacity) are defined on a vault by vault basis (**Recommendation O&E16**).

Although we accept it as an appropriate design change, we do not consider that the conceptual design change from a vertical to a basal drainage system was clearly described and documented in the 2011 ESC. We accept that the basal drainage layer provides supplementary leachate dispersion capacity. However, it was not an option put forward for consideration at LLW Repository Ltd's decision-making workshops (Paulley and Egan 2011). In recommendation O&E4 earlier in this report we recommend improvements to the recording and description of optimisation used to inform future updates of the ESC.

LLW Repository Ltd has sought to optimise the design to minimise impacts arising from leachate overtopping. The predicted leachate overtopping sequence following the degradation of the capping system commences when the rate of leachate generation exceeds the rate of leakage via the vault basal lining system.

In future vaults, when inflow exceeds outflow through the base, leachate is designed to overflow the 1 m high low permeability east and west walls into the basal drainage layer. The internal north and south walls of the vaults will be set slightly higher than the east and west walls to give preferential drainage pathways to the sides, but with ultimate hydraulic continuity along Vaults 9 to

[8] The vertical drain would have comprised a series of deep vertical boreholes containing granular material located in the valley between the vault and trench disposals to the centre of the double dome cap. The boreholes would have extended into the Sherwood sandstone below the repository and would have been constructed shortly before the end of the period of authorisation.

14. Vault 9A will be integrated with Vault 9 as far as possible, but designed as per other future vaults. Prior to construction we will expect LLW Repository Ltd to clarify how Vaults 9 and 9A will be integrated and how leachate will behave between the two vaults. This arrangement supports preferential dispersal into the basal drainage layer to the sides and under the vaults, but also allows for additional capacity, if required, for leachate to flow in a north to southerly direction down future vaults, making use of their leachate management capacity.

In Vault 8 LLW Repository Ltd predicts there will be limited leachate build up due to loss through the base and side walls. However, as a precaution, a spill-over arrangement from Vault 8 to the new Vault 9A drainage system is planned at the western end of the south wall to Vault 8. The overflow level will be set slightly above the 1 m low permeability walls of Vault 9A such that drainage from each vault will preferentially remain within its own area (LLW Repository Ltd 2011b).

To support the assessment of an optimised leachate management sequence, as described in the 2011 ESC, LLW Repository Ltd utilises simple vault scale models to predict leachate behaviour before and after the predicted failure of the capping system. We consider that the leachate management design is adequately optimised. However, both the company and we recognise that the leachate design presented in the 2011 ESC will require further more detailed optimisation and design justification before the placement of the capping system and the construction of future vaults. In ESC-FI-023 we request further development of a vault leachate management strategy, the demonstration of BAT for the design and the development of long-term performance information to support the assessment of the leachate management system.

LLW Repository Ltd does not consider options for improving the effectiveness of the trench leachate collection system in the 2011 ESC, other than as part of wider studies of waste conditioning option. However, we accept that options for improving the trench leachate collection system are likely to be limited due to the age of the trenches and access restrictions. To optimise the trench disposal system the SDP does provide a robust final cap to reduce infiltration. At the time of writing, the company is also developing a strategy for the optimisation of the interim trench cap prior to final capping. We consider that improvement in overall performance and optimisation can be provided by improvements to the interim trench cap and by the final cap when installed. However, we consider that there remains value in considering the potential for improved monitoring and management of trench leachate before installation of the final cap. We set out our expectations for investigations into the long-term functionality, functional requirements and monitoring requirements for trench leachate in ESC-FI-023.

Optimisation of gas collection and management

The engineered cap includes a granular layer dedicated to the function of gas collection and dispersion. The 2011 ESC states that the gas collection and dispersion capacity includes significant redundancy (LLW Repository Ltd 2011b). We sought further information from LLW Repository Ltd to support the 2011 ESC claims, including discussions at a workshop in 2012. In response LLW Repository Ltd provided further information on gas generation rates (Baker 2012). This further information was sufficient for us to complete our review of gas management, although we note that the data would benefit from further update in line with the latest vault waste inventory and trench gas monitoring data. We are satisfied that the data demonstrated low gas generation rates and the sufficiency of the gas collection and dispersion layers to safely manage gas generation throughout the period of authorisation and afterwards.

The Landfill Directive (European Union Directive 99/31/EC 1999) requires relevant sites to manage landfill gases effectively. It does not apply to the LLWR as it does not dispose of directive waste, but we do require the LLWR to meet equivalent standards of performance. In our review, we considered the gas generation potential of existing disposals, taking into account the age of the waste and the nature of future vault disposals. Using the gas flow rate information provided for the trench disposals and taking into account the low organic content of the vault waste, we conclude that the assessed flow rates and volumes of bulk non-radioactive gases (methane, carbon dioxide and oxygen) will be below levels at which active gas management measures would be practical or required.

Overall we are satisfied that the gas management system is adequately optimised for the stage of development of the facility and that passive gas management is sufficient to cope with the low volumes and flows of gas expected to be generated. However, we recognise that LLW Repository Ltd has not yet determined some aspects of its approach to gas collection and dispersion, for example plans for closure of gas vents at the end of the period of authorisation. In ESC-FI-024 we request the production of a proportionally detailed gas management strategy. This strategy should consider the development of gas management infrastructure over the whole period of authorisation, demonstrating ongoing optimisation and provision of infrastructure in line with BAT.

Optimisation of the cut-off wall

LLW Repository Ltd is proposing to install a perimeter cut-off wall that will surround the entire repository and be tied into the final cap. The primary environmental safety functions of the cut-off wall will be to minimise lateral infiltration of groundwater into the repository and to restrict the flow of leachate from the repository laterally and direct it preferentially downwards into the deeper geology. During the 2011 ESC optimisation process, LLW Repository Ltd identified that the main function of restricting groundwater ingress into the repository could be provided by extending the depth of the cut-off wall to 2 m below the base of the vaults (LLW Repository Ltd 2011b). The depth of this proposed cut-off wall design is shallower than the previous 2002 PCSC design and removes the need to key the cut-off wall into low permeability geologies at depths of up to 20 m below ground level. LLW Repository Ltd provides evidence that the reduced depth of the cut-off wall will make construction easier while still limiting lateral ingress of groundwater into the repository from shallow geologies.

We conclude that the 2011 ESC has been able to demonstrate that groundwater ingress and leachate egress from the vaults can be optimised with the installation of a perimeter cut-off wall as proposed. However, because the cut-off wall design and optimisation is based on a combination of limited site investigation information and hydrogeological modelling, as part of the design process, LLW Repository Ltd will need to take account of localised site investigation information to further optimise the cut-off wall depth in accordance with local conditions.

Optimisation of repository scale engineering

Before and after the completion of the final repository cap, leachate and gas will be managed both within individual vaults, trench disposals and across the whole of the repository. The 2011 ESC engineering design incorporates a number of design features that optimise performance at a repository scale, or work together with other design features to achieve optimisation of the whole disposal system.

By necessity, the 2011 ESC uses hydrogeological and water flow models for large scale assessment of repository performance that includes only limited small scale representation of leachate and gas behaviour. This approach has allowed demonstration of repository scale optimisation. We accept that, subject to further detailed design development and substantiation, the 2011 ESC repository design can provide the appropriate standard of radiological protection for the whole life of the LLWR.

We note, however, that the large scale assessment of repository performance used in the 2011 ESC is not always able to take account of the smaller scale complexity of the design, the presence of existing vaults and the potential range of failure and degradation mechanisms. During the design justification process and in the future we would like to see the development of a greater understanding of processes that may take place and influence the performance of the site at a repository scale.

Through the design justification process, as part of the ongoing forward engineering programme and in response to the engineering FIs we have raised, we would like to see further consideration of a number of aspects of repository scale performance, for example:

- the interaction of the vault and trench leachate collection systems after cap degradation
- the configuration of container stacks to facilitate leachate drainage after cap degradation
- the management of leachate and gas before the completion of the final capping system

- the ability to prevent unplanned overtopping to the near-surface environment
- the performance and role of the profiling and drainage systems between the waste and the engineered cap
- demonstration of the ability to manage leachate management after cap failure at any location on the restored repository

2.2.5. Optimisation of the extended disposal area

LLW Repository Ltd presented a separate assessment of the extended disposal area (EDA) comprising 6 further vaults (Vaults 15-20) in addition to the RDA, placed to the immediate south-east of the RDA, lying adjacent to Vault 14 and the southern end of the trenches (LLW Repository 2011h).

To develop the EDA concept, LLW Repository Ltd undertook a siting study that assessed the most appropriate location on the LLWR site to accommodate the additional inventory (LLW Repository Ltd 2011h). Within the constraints of the site boundary and the predicted KRWI, we agree that the company has optimised the proposed EDA location to take account of the main environmental safety factors.

Most of the issues discussed in relation to optimisation within this report apply equally to the RDA and the EDA and so will not be discussed again here. Additionally, the EDA is not anticipated to be required for a number of decades and so we would expect further optimisation of the design and operations during this period, taking account of learning from the RDA and elsewhere. Therefore, as for the RDA, we consider the EDA to be appropriately optimised for its stage of development at this time.

Prior to its operation we expect LLW Repository Ltd to ensure appropriate emplacement strategies are in place for the EDA and to determine whether any further controls are required. We note that it is projected the construction of the EDA would increase the time before final capping is placed over the southern sections of the trench disposals. Any optimisation strategy of the interim trench cap needs to take into consideration any increased time before the placement of the final cap.

2.2.6. Optimisation of the overall engineering design

Overall, as discussed in the previous sections, we are satisfied that LLW Repository Ltd has developed an optimised design appropriate for the stage of development of the facility. The company and we have noted that, as is normal practice, this design will require further detailed development in the run up to construction of the cap and any further vaults and that as part of this process it will be further optimised on an ongoing basis. We have raised a number of FIs where we expect to see specific areas of further work. Specific aspects of the design that we do expect to see further detailed development and optimisation of include the waste container design, measures to protect waste before final capping and measures to prevent unacceptable cap settlement such as cap design, minimisation of container voidage and consideration of stack heights. Each of these issues must be fully addressed within reasonable timescales or prior to construction of the final cap and we detail our requirements within FIs ESC-FI-001, ESC-FI-025 and ESC-FI-027.

2.3. Engineering

LLW Repository Ltd presents an optimised SDP in LLW Repository Ltd (2011b). The SDP represents LLW Repository Ltd's current view of how the repository will be developed as well as providing the baseline against which all performance modelling and assessment presented in the 2011 ESC was carried out.

The GRA does not specify regulatory expectations for the performance of engineered systems. Instead, the GRA principles and requirements relate primarily to the ESC and infer the need for appropriately engineered systems. Thus, the design and performance of the engineered systems are informed by and must meet the ESC objectives. In our review, we have assessed the conceptualisation of the engineering design, the evolution of engineering performance objectives and the appropriateness of these objectives to meet GRA principles and requirements.

Our review of the 2011 ESC engineering has included the Level 2 engineering design report (LLW Repository Ltd 2011b) and Level 3 documents on cap settlement (Tonks 2011) and elicitation of uncertainties (Jackson et al. 2011). We required further information to complete our review which we requested via an RO (ESC-RO-SUE-009).

We have also reviewed design changes associated with the container condition survey in this report and Environment Agency (2015j) and have reviewed the engineering forward programme provided in response to ESC-RO-SUE-009 (Shaw 2013). Outputs from container condition investigations undertaken by LLW Repository Ltd (Jefferies 2012, 2013a), with relevance to engineering designs, were also reviewed.

Prior to the commencement of engineering works we will undertake regulatory review of detailed aspects of the design and construction programme at agreed stages in the design justification process. This ongoing review will seek to ensure that the developing design maintains alignment with the engineering performance assumptions set out in the 2011 ESC and continues to meet our requirements.

2.3.1. Engineering design review

The construction, operation and restoration of the repository, and the engineering design work that will accompany it, are proposed to cover a period of more than 100 years. We do not expect the engineering design of the facility presented in the 2011 ESC to provide all the details of the final facility to be constructed. Many of the engineered systems will not be built for a long time to come and it is right that development of fully detailed designs is deferred until closer to the point of construction, such that knowledge and experience that may not yet be available can be applied. At present, some of the engineered systems could be considered as relatively conceptual in nature and will be developed to the required level of detail before construction. As discussed earlier in this document, we consider that the stage of development of the designs is appropriate for use in the current ESC and for the stage of development of the facility, with the expectation of further development in accordance with the SDP.

The design needs to:

- be consistent with the repository concept
- provide realistic engineering performance values for use in the performance assessment
- be based on a realistic development, operation and restoration sequence taking account of constraints such as waste input rates and container integrity
- take account of existing constructed engineered systems and site-specific constraints
- be progressed to a final design ready for construction, supported by any necessary research requirements, performance monitoring and the design development and substantiation process

A major element of our review has been gaining confidence that the 2011 ESC design can evolve during the design development and substantiation process while maintaining the ESC performance objectives. During our review we found it necessary to request further information on:

- mechanisms for implementing the design
- provision of underpinning research and development and performance monitoring
- how the as-built repository will achieve the performance claimed in the 2011 ESC

We did this through ongoing liaison with LLW Repository Ltd, an engineering workshop used to clarify engineering design decisions presented in the 2011 ESC and a RO (ESC-RO-SUE-009) through which we sought a forward engineering programme to address a number of our questions. LLW Repository Ltd's responses to these actions are discussed in the sections below.

We note that Vault 8 restoration works may begin in the next 2 to 4 years. Therefore, we have sought reassurance that the design can be developed into a final construction design over this timeframe.

Engineering workshop

We held an engineering workshop with LLW Repository Ltd in January 2013 with the objectives of:

- gaining an understanding of more detailed aspects of the design
- understanding areas of the design that require further development work
- challenging design assumptions and gaining confidence in the design process
- clarifying regulatory priorities

At the workshop we were able to query LLW Repository Ltd's design assumptions and approaches used for developing the SDP at a greater level of detail than set out in the 2011 ESC. The workshop discussions provided clarity and helped to address many of our questions. It was evident from the workshop that much of the information that we sought was already available and that LLW Repository Ltd already had well developed plans to progress engineering design development work in many of the areas in which we had identified an interest.

2.3.2. Our review of engineering issues

Following the engineering workshop, we summarised our outstanding questions regarding the development and substantiation of the engineering design in ESC-RO-SUE-009. Our questions were consolidated into discrete thematic groups, covering:

- demonstration of the long-term robustness and performance of the final cap
- the functions and performance of the vault and trench leachate systems and infrastructure
- engineering aspects of mitigation measures designed to prevent overtopping
- substantiation of novel and unique design concepts

Our main queries were how LLW Repository Ltd would:

- manage progress from the more conceptual design presented in the 2011 ESC to the as-built design
- validate the environmental safety performance assumptions presented in the 2011 ESC
- identify further detailed optimisation requirements

In addition, we sought clarification of:

- design concepts to allow us to complete our review of the 2011 ESC design
- the scope of the engineering programme
- the nature of the engineering design substantiation process to take the design from concept to implementation

We also asked LLW Repository Ltd to provide a comprehensive site engineering forward programme. In response the company provided this programme in Shaw (2013).

The engineering forward programme identifies important engineering aspects that need to be addressed before construction and where further detailed optimisation is required. It also accommodates scope for regulatory review and feedback on areas of regulatory interest. It proposes a combination of investigations, design processes and desk studies to address outstanding issues. The work programme will address the specific questions that we raised in our ESC review, ESC-RO-SUE-009 and that LLW Repository Ltd has identified as outstanding. However, the engineering programme does not set out all the activities that may need to be carried out throughout the period of authorisation of the LLWR, and the programme will be subject to iterative updates as the design is developed further. It was also recognised that the outcomes of programmes outside of the engineering forward programme would also generate information of use in the engineering design justification process. We consider it important that an effective linkage between the ESC and the developing design is maintained.

In addition to the issues we raised in ESC-RO-SUE-009, LLW Repository Ltd identified the need for a substantial engineering programme to investigate the causes and consequences of the observed degradation of some containers and the ullage created within some containers by grout settlement (Environment Agency 2015j).

2.3.3. Engineering forward programme

We sought a high level, but comprehensive, engineering forward programme that addresses the questions we raised. LLW Repository Ltd's engineering forward programme addresses our questions and other areas of the engineering design needing further investigation and development. It will feed into the ongoing evolution and optimisation of the engineering design and will inform long-term engineering studies and future updates of the ESC. The engineering forward programme will need to cover the construction of both the final repository engineering systems and temporary features utilised during the staged restoration sequence.

The engineering forward programme covers the period leading up to the start of capping works (Shaw 2013). Along with the container investigation programme, the engineering forward programme is designed to specify construction details that will enable all engineering works to meet the performance objectives of the 2011 ESC. We consider that this programme could also provide a framework suitable for further optimising the engineering design.

The scope of the engineering programme includes:

- container optimisation, linking to the ongoing container investigation programme
- specification of the detailed design of the leachate system
- specification of construction materials
- design development to ensure the long-term robustness and performance of the final cap
- detailed evaluation and optimisation of the Vault 8 closure plan, taking into account the long-term performance objectives of the system, the current status of the containers and the benefits of disposing of more containers on top of those already disposed of
- providing construction details of the temporary and permanent works showing that they meet the performance objectives of the 2011 ESC and have been subject to an optimisation process
- site and laboratory based research and development needed to allow the development of the engineering design
- the identification of engineering performance monitoring needs and delivery mechanisms

LLW Repository Ltd has presented an engineering forward programme that seeks to address the questions we raised during our review of the 2011 ESC and to support the details required for construction. Where the engineering forward programme does not fully address areas we have identified, we have raised further FIs to detail our expectations (as discussed further below and described in Appendix 3). We will work with LLW Repository Ltd to make sure that the programme provides engineering information sufficient to meet the requirements of the GRA at the appropriate stages of repository development (Fairhurst 2013).

The engineering forward programme includes a series of review points and associated design justification points, at which we will review the engineering design before it progresses further. At these review points and in ongoing liaison meetings with LLW Repository Ltd we will make sure that the design, as it develops, continues to meet our expectations and the requirements of the GRA. Also, we will aim to assure ourselves that LLW Repository Ltd’s approach remains consistent with the 2011 ESC and with good practice.

Before starting the Vault 8 restoration, LLW Repository Ltd's engineering design development and justification process will need to provide enough information to demonstrate that the individual features and the engineered system as a whole will perform acceptably, in line with the 2011 ESC and are optimised utilising BAT. LLW Repository Ltd will need to:

- provide adequate responses to the issues raised on the engineering programme
- subject the evolving design to appropriate justification and review as set out in LLW Repository Ltd's Repository Site Procedures (LLW Repository Ltd 2013c)
- continue to subject all aspects of the engineering design to an optimisation process
- increasingly take account of detailed site and material specific factors
- take account of material availability and new technologies/techniques as the design evolves
- take account of operational drivers such as waste input rates and container optimisation to provide a flexible restoration design
- demonstrate progress against the engineering work programmes requested in our FIs

- take account of construction experience and the results of an engineering performance monitoring programme

Throughout the programme of work LLW Repository Ltd will need to maintain effective links between the design process and the ESC performance objectives. To this end we consider the recent re-organisation to place the engineering function, Safety and Environmental Safety Case Team (along with the Monitoring and Site Characterisation Teams) into the same functional support department to be a positive step.

We expect LLW Repository Ltd's engineering forward programme to provide the engineering framework and justification needed to meet the control measures and functions set out in Table 3.1 of LLW Repository Ltd (2011i).

On completion of our review we are confident that LLW Repository Ltd has identified areas within the engineered design that require further detailed development and has put in place a comprehensive engineering programme and supporting arrangements to address these needs. We consider that this engineering programme, together with LLW Repository Ltd's wider design development, optimisation and justification process is sufficiently robust to provide an optimised detailed design that aligns with the performance objectives of the 2011 ESC.

2.3.4. Assessment and substantiation of the engineering design

The GRA does not prescribe the use of a safety function approach; however, attributing safety functions to the repository engineering features may help clarify the ESC. This is especially relevant where engineering systems and barriers either perform multiple roles or have changing functions over time.

LLW Repository Ltd provides a summary of engineered systems and their environmental safety functions in Table 3.1 of the 2011 ESC Level 1 report (LLW Repository Ltd 2011i). This summary is at a high level. These environmental safety functions for the engineered systems are not always clearly presented throughout the 2011 ESC.

In ESC-RO-ASO-005 we queried why a formal environmental safety function approach had not been developed for the 2011 ESC. To improve clarity around environmental safety functions, we asked LLW Repository Ltd to describe the environmental safety concept for the LLWR and provide further information to extend and enhance the list of environmental safety functions in Table 3.1, together with an indication of the timeframes over which they are claimed to perform.

In response, LLW Repository Ltd noted that much of the material on the performance of engineered systems is distributed through various Level 2 and Level 3 documents and is not drawn together comprehensively in either the main Level 1 report or in the relevant Level 2 report (Baker 2013). We recommend that future updates of the ESC provide an effective linkage between the environmental safety objectives and the detailed engineering performance specifications. This linkage will assist in the optimisation and design process (**Recommendation O&E17**).

The Level 1 report states that 'An important aspect of developing, comparing and selecting a set of control measures has been developing a clear understanding of the safety functions of the different control measures and the qualitative or quantitative effects that they might have on environmental impact' (LLW Repository Ltd 2011i). The repository engineered systems are the main measures of this type.

We found the description of the site engineering (LLW Repository Ltd 2011b) to be poorly linked to the environmental safety functions of each component of the engineered systems. We also found it difficult to establish a clear link between the environmental safety functions of the components of the engineered systems identified in Table 3.1 of the Level 1 report (LLW Repository Ltd 2011i) and their performance objectives. For example, the ‘gas collection layer’ (that is incorporated below the base of the cap) has an environmental safety function to collect and discharge gases generated from the waste in a prescribed manner to prevent isolated discharge of radioactive gases, gas pressure build-up and undesired lateral release of gases. In the 2011 ESC, LLW Repository Ltd did not specify the minimum gas permeability needed to achieve the performance objective or identify the likely gas flow rate and volume from the waste mass. Thus, it was difficult to assess the ability of the gas collection layer to achieve the performance objective without requesting further information (as discussed in Section 2.3.11).

In addition, Table 3.1 does not identify all the individual components of systems for which environmental safety functions are claimed. For example, it does not include the basal drainage layer that is designed to help divert leachate away from the near-surface environment in the case of overtopping, although this is discussed elsewhere in the 2011 ESC (for example, in LLW Repository Ltd 2011b). In other parts of the 2011 ESC, a wider range of environmental safety functions are attributed to the cap than listed in Table 3.1. In all these instances, the other environmental safety functions not listed in Table 3.1 are valid and reasonable.

LLW Repository Ltd recognises the need to balance qualitative and quantitative reasoning in presenting the engineering design (LLW Repository Ltd 2011b, 2011i). However, we consider that the 2011 ESC as a whole fails to link the qualitative environmental safety objectives for the design adequately with any quantitative evidence of performance. For example, for the qualitative objective to contain the waste source, the 2011 ESC states that the final cap will be 'sufficiently robust'. This qualitative statement is not backed up with evidence from, for example, bio-intrusion studies, to validate the robustness of the cap as a whole and the dedicated functional layers. We have raised an FI that seeks design justification for each functional element of the capping system (ESC-FI-027), with emphasis on providing evidence to support performance claims.

In future updates of the ESC we recommend that LLW Repository Ltd demonstrates how the specified objectives for all the environmental safety functions provided by the engineered system can be met by the chosen engineering design. This demonstration might include the following information:

- realistic material performance properties for the as-built engineered system
- long-term performance projections
- design assessments demonstrating system performance together with performance ranges used to inform assessment models
- improved alignment of elicited engineering performance parameters with the materials identified in the proposed material specification document (Shaw 2013)
- monitoring and investigation programmes to demonstrate performance
- identification of the environmental safety functions of each component of the engineered system throughout the evolution of the repository

LLW Repository Ltd should consider identifying specific engineering safety functions for each component of the repository engineering design to better inform the design development and justification process. Where appropriate the changing function of the engineering component should be recorded. Where engineering systems or barriers provide multiple safety functions we recommend that LLW Repository Ltd should differentiate between the primary environmental safety functions and the secondary environmental safety functions (**Recommendation O&E18**).

Although the assessment and presentation of engineering safety functions would have benefited from clarification, we conclude that the 2011 ESC has adequately identified appropriate engineering and substantiated its role and performance.

2.3.5. Research and development

The 2002 PCSC engineering design was supported by an extensive engineering research and development (R&D) programme that investigated material and system performances as well as engineering failure mechanisms (BNFL 2002d). However, the previous repository operator and LLW Repository Ltd have not pursued an engineering R&D programme since the submission of the 2002 PCSC.

To support the 2011 ESC LLW Repository Ltd primarily uses a combination of existing engineering performance information available in the 2002 ESCs, together with international and landfill best practice and engineering information elicited using experts. We consider that this approach has been sufficient to support the development of the engineering design to the level of detail required at this time. This has allowed sufficient detail and supporting evidence to be gathered to support performance assessments in the 2011 ESC and to meet the expectations of the GRA. Through this work the company has demonstrated that elicitation studies can be used to generate long-term performance parameters for engineered systems that have degraded.

As the engineering design is further developed in the period leading up to construction, we consider that LLW Repository Ltd could make further use of a dedicated R&D and engineering monitoring programme and use of the outcomes of the R&D programme in support of the 2002 ESCs. We consider that a range of R&D and an engineering monitoring programme is likely to be required and would be beneficial in supporting and informing the engineering design as it is implemented and developed further.

Performance information derived from practical site and laboratory research programmes can support performance assumptions used in the 2011 ESC in the run up to construction. We consider that there may be benefits in setting out a high level engineering R&D programme that considers all areas of engineering work during the period of authorisation such that it can be planned over long timescales. Outcomes from this programme will support the development of the engineering design, feed into the optimisation process and support the performance assessment of the engineered system in the long-term (ESC-FI-026 and ESC-FI-027).

In the shorter-term, in the run up and during construction of the final cap and future vaults, we consider it important that LLW Repository Ltd establishes both an engineering performance monitoring programme and an R&D programme as described in ESC-FI-026. The engineering performance monitoring programme should consider including field trials where appropriate to:

- support and inform the design of the cap
- evaluate the degradation of engineering materials
- inform development of the final detailed engineering design, which is fully consistent with the ESC
- increase understanding of engineering performance
- support substantiation of the design
- support assessment within future updates to the ESC

We would like to see the development of a strategy that links research needs, performance assessment requirements and the construction process to demonstrate that the performance claimed in the ESC can be achieved.

During the development of the vault disposal concept, BNFL undertook destructive testing of a number of grouted containers packed with representative waste types. The containers were sectioned using diamond wire cutting. The output of this investigation is described in Wood (2000). The learning from this investigation was used extensively in both the 2002 ESC and subsequent container condition investigations. Because of the importance of the grouted waste form in providing a number of safety objectives, notably minimising cap settlement, we consider it important that LLW Repository Ltd considers how destructive investigations of the waste container may further inform the ESC, including consideration of the nature and extent of grout distribution throughout the grouted waste form. We recommend that LLW Repository Ltd considers undertaking further destructive container investigations, similar or complementary to those carried by Wood (2000), to validate and further inform the ESC (**Recommendation O&E19**).

We understand that LLW Repository Ltd has carried out an initial assessment of the practical use of non-destructive container inspection methods (Jefferies 2013b). We consider it important that LLW Repository Ltd continues to review the use of these methods to meet its operational information needs, drawing on experience from other industries and taking account of developing technologies (**Recommendation O&E20**).

2.3.6. Elicitation

LLW Repository Ltd uses elicited values to take account of how important features of the engineered systems will perform over an extended time (Jackson et al. 2011). Aspects covered in the elicitation exercises include cap infiltration and the performance of the vault base and walls, the vertical and basal drainage systems and the cut-off wall. Uncertainties were also elicited, with outputs from the exercise comprising minimum, most likely and maximum values for engineering properties at significant time points in the evolution of the site. We provide our review of LLW Repository Ltd's use of the elicitation process in the ESC assessment in our Safety Case Management review report (Environment Agency 2015b).

We accept that the elicitation approach used is appropriate for describing the evolution of engineered systems where empirical values are not available. We consider that the elicited engineering performance values are realistic and correspond to the current conceptual state of the engineering design. For an intact engineered system, the use of elicited values with associated probability distribution functions provides reassurance that the assessment models are based on a realistic distribution of performance values for an intact repository.

Jackson et al. (2011) present the outcome of the elicitation process with a limited commentary describing some of the rationale for selecting the elicited values. The degree of conservatism in the elicited values is not clear from this report alone. Because of the importance of the elicited values presented in the 2011 ESC we recommend that, where future updates of the ESC use elicited values, they also include a wider and deeper commentary on the elicitation process and identify the sources of information used to inform the decision-making, or provide clear references to such information. We have raised ESC-FI-029 to request improvements to the management of elicited data in future studies as well as procedures for reviewing and updating elicited values.

From the 2011 ESC it appeared to us that the elicited data presented focus on performance values that reflect the gradual degradation of an engineered component over time rather than localised or rapid degradation from discrete failure mechanisms. However, LLW Repository Ltd has clarified to us that discrete failure mechanisms were considered, but presented as averaged properties that represent the aggregated affect of those discrete failures over time. We consider that these elicited data bound the failure mechanisms and their environmental implications. However, we believe LLW Repository Ltd could do more to present any wider considerations and approaches used to arrive at these data, for example presenting the range of localised failure mechanisms that were considered, along with a demonstration of how they are adequately bounded by the data used. Failure mechanisms should also be further informed by ongoing work on cap settlement and container condition. Because of the importance of the cap in minimising infiltration into the waste mass, LLW Repository Ltd should make sure that elicited data are consistent with and, where possible use outputs from, future engineering performance assessments (**Recommendation O&E21**).

The 2011 ESC engineering design includes granular infilling of the vertical spaces between containers in Vault 8 and no infill for future vaults. LLW Repository Ltd assumes that all horizontal and vertical spaces between containers are capable of transmitting leachate, with most of the flow passing through spaces between container stacks. Jackson et al. (2011) present elicited values for flow in the gaps between containers and flow in the granular infill. These values are only provided for the present day and for the very long-term after complete failure of the drainage layer, container structure and grouted waste. In the very long-term, infiltration is assumed to be entirely through the degraded waste mass, with the vault waste exhibiting flow properties similar to gravel. We consider that the ESC would benefit from better presentation of the evolution and failure processes that may happen between implementation of the as-built design and complete failure of the drainage system and waste mass in the future. In ESC-FI-023 we have asked LLW Repository Ltd to further investigate realistic leachate drainage failure and degradation mechanisms; we expect the outcome of these investigations to contribute to improved understanding of the long-term degradation of engineered leachate systems.

The results of the elicitation exercise were used to parameterise the assessment calculations to take account of the evolution of the performance of the engineered barriers over time (Jackson et al. 2011). From the information presented in the 2011 ESC, we considered that several elements of the elicitation exercise are not clear, such as:

- Whether the purpose of the elicitation was to derive parameter ranges for specific disposal facility features or whether it was also to develop views on how the near field may evolve in the future?
- Whether experience from operation of the LLWR or other disposal sites was used to underpin the assumptions made at the elicitation workshop?
- Why it was considered appropriate to assume that the engineered features degraded continuously? Was the potential for any 'cliff edge' effects in performance considered?

- Whether the implications of degradation of one engineered feature on another were considered?

We recommend that LLW Repository Ltd considers the need for further investigations into the timing, mechanisms and uncertainties associated with the failure and degradation of performance of engineered systems during and after the period of authorisation, to support elicitation exercises. Any such investigation should be based on actual material specifications used within the design, taking account of ageing, environmental factors and any synergistic effects. Consideration should be given to the clarity of the documentation of evidence supporting engineering degradation mechanisms and timing within the ESC (**Recommendation O&E22**).

Some of the elicited values presented for the engineered systems do not appear to fully align with the engineering materials destined for potential use; for example, both compacted clay and Bentonite enhanced soil (BES) have been identified as the low permeability component of the cap. The engineering programme (Shaw 2013) includes the development of a specification for significant engineering materials. We expect elicited engineering values to be revisited where any changes are made.

During our review of the 2002 ESCs, we raised a number of IAFs that sought reassurance and design validation for the components of the engineered system, in particular relating to reducing reliance on elicited performance data in favour of data derived from empirical evidence (IAF SDE_002.2, IAF SDE_004.1, IAF SDE_006.1 and IAF SDE_007.3; Environment Agency 2015h). The 2011 ESC appropriately continues to make significant use of elicited data. However, we consider that LLW Repository Ltd should continue to address these recommendations in the run up to construction. Our expectations for increased use of site derived engineering performance data wherever viable and beneficial to do so are outlined in the engineering FIs (see Appendix 3).

Elicitation played an important role in informing the assessment process and we consider that the 2011 ESC could have been improved by inclusion of further information on the elicitation process within the ESC document suite, or by improved referencing to more detailed records. In ESC-FI-029 we ask for the clarification of the procedure for reviewing and updating the elicited values used to support the ESC performance assessment. This procedure should make sure that the most up-to-date and relevant values are used in the ESC.

2.3.7. Novel engineering design

The LLWR vault and trench restoration engineering design is mostly based on technologies and configurations similar to those used in other worldwide surface repositories and hazardous waste landfills. We consider that LLW Repository Ltd has appropriately considered and made use of these technologies. The main difference between the performance requirements for landfill engineering and the LLWR engineering is the timescale over which it is required.

Characterisation of the long-term performance of engineered systems is a significant area of uncertainty within the 2011 ESC. Although LLW Repository Ltd can make use of evidence of engineering performance from landfills and surface repositories elsewhere, these data do not cover the extended periods over which performance must be achieved and assessed. These extended time periods have appropriately been addressed by elicitation exercises. However, we consider that in the run up to construction and during the period of authorisation, further site-specific or experimental evidence should be gathered wherever practicable to help substantiate the claimed performance of engineered systems over extended periods.

In ESC-FI-023 we lay out our expectations for LLW Repository Ltd to further investigate and substantiate the performance of the leachate systems. We expect LLW Repository Ltd to clarify the role and significance of the basal drainage layer and the claimed performance of the granular materials that will be used in its construction. The company should consider possible degradation mechanisms over extended periods and provide evidence to support performance of the drainage layer and the leachate system as a whole.

Although the final engineered cap is largely based on proven landfill engineering design, the LLWR cap will be expected to perform for longer periods than a typical landfill. The proposed cap is also relatively complex in design, with a large number of discrete cap layers proposed, that will need to be joined across restoration strips as they are constructed over a number of decades. We expect

LLW Repository Ltd to demonstrate the effectiveness of the design and construction sequence before construction.

The cap over the vaults also differs from typical landfill designs in that settlement may be initiated by container failure after an extended period and the behaviour of the underlying waste may differ in other ways. Significant work has been completed by LLW Repository Ltd and continues to fully understand the settlement potential of the vault waste and the implications on cap design (Tonks 2011, Jefferies 2013a, Shaw 2013). We have outlined our expectations for this further work before construction begins in a number of FIs (ESC-FI-001, ESC-FI-026 and ESC-FI-027).

In ESC-FI-026 we seek clarification from LLW Repository Ltd on the use of performance information from any future forward programme or engineering monitoring programme to demonstrate the performance of novel design aspects and materials in more detail than presented in the 2011 ESC. Where possible the R&D programme should explore the long-term performance of materials, and investigate novel aspects of the design and potentially significant engineering failure mechanisms and uncertainties.

2.3.8. Engineering performance assessment

An engineering performance assessment (EPA) is a formalised approach to identify and assess the effect of engineering failure mechanisms on the performance of a repository and to inform the environmental safety assessments. The 2002 PCSC included a substantial EPA that investigated the performance and failure mechanisms of engineered systems and the associated effect on site environmental safety (BNFL 2002d).

In the 2011 ESC, LLW Repository Ltd chose not to use an EPA to identify and assess scenarios and processes that could affect the performance of the repository engineering. Instead, LLW Repository Ltd relied on identifying relevant features, events and processes (FEPs) and related uncertainties, using elicited data to take account of engineering performance. We consider that LLW Repository Ltd should consider use of a proportionate EPA framework to assist the development and validation of a final engineering design and incorporate this into future ESC updates. This EPA should take into account the outputs of different engineering work streams LLW Repository are undertaking (ESC-FI-026).

Although we accept that the EPA presented within the 2002 ESC may have been too complex for practical application within the ESC, we consider that an EPA approach may be better able to address the affects of various failure scenarios on system performance. In particular, an EPA framework may be able to better address potential localised engineering failures.

In the 2011 ESC, the process of setting performance objectives focused on assessing the environmental safety implications of the failure of individual engineered systems in the long-term. Although the 2011 ESC has been successful in this respect, we believe it could be further developed to investigate whether the evolving engineered systems can meet performance objectives prior to the point of eventual failure. The ESC needs to demonstrate that realistic failure scenarios have been identified and that the engineered systems have been optimised taking these scenarios into account.

We ask LLW Repository Ltd to reconsider developing a comprehensive EPA framework in ESC-FI-026. We note that LLW Repository Ltd has previously considered this approach but concluded it has shortcomings, some of which we recognise. Should an EPA be taken forward the company should include the results of any EPA in future updates of the ESC and use them to inform the repository assessment process and the engineering performance monitoring programme. Where appropriate, LLW Repository Ltd should also use the outputs of the EPA to inform the failure scenarios chosen for assessing the consequences of future human intrusion.

LLW Repository Ltd's assessment of cap performance in the 2011 ESC assumes gradual loss of functionality of the final cap after a period of several 100 years, with failure resulting in increased infiltration into the waste mass. Following further work on container condition and settlement potential (Jefferies 2012, 2013a), LLW Repository Ltd has stated that it will undertake further work to assess the adequacy of the final cap, taking into account potential settlement profiles and considering a range of potential cap failure scenarios (Shaw 2013). This work will be used to finalise plans for the stacking of waste and any necessary cap adjustments to achieve the necessary performance. Due to the importance of the stability of the final cap we have detailed our expectations for this further work within a future EPA in ESC-FI-027, including consideration of the timing, nature, location and extent of any cap failures, including performance reductions that may occur prior to final cap failure. We expect the development of the understanding of cap failure to be informed by the outputs of the ongoing container optimisation and condition work.

2.3.9. Performance monitoring of engineered systems

The 2011 ESC does not provide details of the proposed programme for monitoring the performance of the engineered barrier system or gathering site-derived performance information. This information is needed to demonstrate engineering performance, but may also provide information to underpin the engineering design and allow LLW Repository Ltd to respond to unexpected engineering behaviour. LLW Repository Ltd should use the outputs from the programme to understand the performance and evolution of the engineered systems, and we consider it essential that suitable outputs should be available to inform the systems design before construction. For example, the 2011 ESC does not set out how as-built performance of the engineered capping system will be monitored to be able to confirm the ESC assumptions and inform the design of later vault caps.

We ask LLW Repository Ltd to prepare a programme for monitoring the performance of the engineered barriers in ESC-FI-026. This should identify those parts of the engineered systems requiring performance measurement or uncertainty reduction. Arrangements should be in place to ensure that the ESC takes account of the outputs of the monitoring programme.

LLW Repository Ltd will manage and maintain the engineering design of the repository throughout the period of authorisation to meet the environmental safety objectives of the ESC and to sustain the required performance. To achieve this, the company operates an asset care and maintenance system which it is further developing. During our review we queried how the company planned to manage change control, including that related to infrastructure and equipment, to make sure the assumptions within the ESC continue to be met (ESC-RO-SCM-001). In response LLW Repository Ltd provided further details of how it planned to manage change and the future review, update and implementation of the ESC (LLW Repository Ltd 2013f). It identified the approaches it will use to manage and maintain environmentally critical engineered systems throughout the lifetime of the permit (LLW Repository Ltd 2013d).

2.3.10. Engineering FEPs and uncertainty

The 2011 ESC includes an interim list of FEPs affecting the repository and its evolution (Lean and Willans 2010). LLW Repository Ltd developed a FEP and uncertainty tracking system that documents these FEPs, including FEPs related to the engineered systems, and the associated uncertainties (LLW Repository Ltd 2013e). The tracking system includes details of the significance of uncertainties, how they have been treated in the 2011 ESC and proposals to reduce them where appropriate.

The FEP and uncertainty tracking system considers engineering performance at the scale of the repository, describing engineering systems rather than individual component behaviour. In contrast, the original FEPs list, as documented in Lean and Willans (2010), included a more comprehensive range of FEPs, including FEPs related to the performance of individual components of the engineered systems, such as the cap and cut-off wall performance. These FEPs have not been transferred to the more recent FEP and uncertainty tracking system and no uncertainties have been attached to them. Although we consider that FEPs and uncertainties have been adequately addressed in the 2011 ESC, we consider that the level of uncertainty associated with the performance of the engineered systems could be better captured in future by considering engineering uncertainty not only at a repository scale, but also for individual components of engineered systems. We recommend that LLW Repository Ltd brings the engineering performance FEPs identified in Table A1.4 of Lean and Willans (2010) into the FEP and uncertainty tracking system, or a suitable future alternative system (**Recommendation O&E23**).

Although LLW Repository Ltd acknowledges that uncertainty in engineering performance is high in certain areas in the FEP and uncertainty tracking system, we consider that the tracking system does not adequately discuss the current level of understanding of engineering performance and failure mechanisms. We expect the engineering forward programme and design justification process to seek to reduce these uncertainties, focussing on those of most significance to the outcome of the ESC.

In particular, FEPs on 'Vault design (overall) - V8/9' (GW_NF_SE_SSF_02) and 'Vault design (overall) - future vault design' (GW_NF_SE_SSF_03) do not adequately identify the current high level of uncertainty in the performance of the vault leachate system and basal granular drainage system. We would like to see the current uncertainty in the performance of the leachate management system and basal drainage system considered further in LLW Repository Ltd's FEP and uncertainty tracking system, together with suitable links to the engineering programme (**Recommendation O&E24**).

The FEP on 'Vaults - waste forms and containers' (GW_NF_V_SSF_02) only considers uncertainty associated with the waste form. LLW Repository Ltd does not discuss uncertainties in the extent and timing of container stack settlement resulting from waste settlement, container degradation and voidage created within containers by grout settlement. Based on the outcome of the container investigation programme (Jefferies 2012, 2013a) we recommend that a specific FEP is developed for the magnitude and timing of past and future container settlement (**Recommendation O&E25**).

In future updates of the FEP and uncertainty tracking system (or future alternative systems) we expect to see an increased level of detail in FEPs covering the engineered system and its performance, and the associated uncertainties. These FEPs should be effectively linked to the developing design and uncertainties associated with it (**Recommendation O&E26**).

2.3.11. Performance of the individual components of the engineered system

The following sections describe the outcome of our review of the performance of individual components of the engineered system. They focus on the performance that LLW Repository Ltd has attributed to these components and provide feedback on detailed design aspects.

The 2011 ESC repository design uses several passive engineered systems to provide environmental protection over an extended period. The performance assessment takes account of the anticipated evolution and eventual failure of the engineered systems. This approach is essential to take account of the extended period over which LLW Repository Ltd expects the repository to function. Our review examined the expected lifetime of the engineered systems, the performance of materials, and failure mechanisms together with their implications for the performance of engineered systems.

Drainage and leachate strategy

The restored repository will be a complex interlinked system for which a leachate management strategy is needed during the period of authorisation and subsequently. During the operational period, LLW Repository Ltd will collect and remove leachate from the trenches and vaults. As the repository is progressively capped, the amount of leachate generated is expected to reduce significantly; during this period the company will continue to monitor leachate levels. The 2011 ESC assumes that the leachate collection efficiency in the vaults during this period will be 100%.

Over a period of several 100 years after capping, the performance of the engineered cap is expected to degrade to a point at which infiltration through the cap will exceed the discharge of leachate through the base of the repository. The 2011 ESC repository concept takes account of the anticipated reduction in cap performance and seeks to deal with the increased leachate input by diverting leachate into the perimeter and basal shallow geology.

As part of the optimisation of the leachate systems, LLW Repository Ltd has identified 4 main objectives to enable leachate to be dealt with effectively during the period of authorisation and subsequently (see Section 2.2.4 and LLW Repository Ltd 2011b). The following sections discuss our review of the ability of the leachate systems to meet these objectives.

Vault leachate management

In Vault 8, leachate flows between containers and is collected in an under-slab leachate collection layer with 3 discrete collection points. For Vault 9 and future vault designs there is no under-slab collection layer; leachate flow and collection happens entirely in the inter-container spaces feeding into low point sumps. This design differs from typical non-radioactive non-hazardous and hazardous landfills where leachate is collected in a granular basal layer.

The objectives of the vault leachate management system identified in the 2011 ESC include:

- collecting and removing 100% of leachate across the whole of the vault footprint during the period of authorisation to minimise exposure of the waste to leachate
- maintaining the waste in a dry state throughout the period of authorisation
- preventing perched leachate overtopping the 1 m high vault side wall (from Vault 9a onwards) throughout the period of authorisation
- providing appropriate monitoring and sampling information on the composition, height and volume of leachate in each vault throughout the period of authorisation

In addition to meeting the 2011 ESC objectives described above, leachate within the LLWR needs to be managed in accordance with BAT.

While we consider that the company's leachate management strategy and design is reasonable and capable of achieving the required performance, we recognise that further, more detailed design and design justification is required before full implementation to fully support the assumptions made within the 2011 ESC. We expect the company to address the following issues in the leachate management strategy before the start of Vault 8 restoration:

- provision of improved design and performance information for container configuration and drainage systems, for both existing and future vaults
- provision of further performance validation for the assumed 100% leachate collection efficiency in the vaults throughout the period of authorisation
- the need for further consideration of leachate drainage behaviour within the waste as the rate of cap infiltration increases following cap degradation
- the need to demonstrate that leachate levels will behave as anticipated across the whole of the vault footprint
- the need to understand and to take account of the interactions between existing and future vaults

We set out our expectations for the provision of a leachate management strategy in ESC-FI-023. We require:

- a leachate management strategy covering the existing vaults, future vaults, trenches and the restored repository
- demonstration of BAT for managing leachate during the period of authorisation
- leachate performance information to support the 2011 ESC assessment and validate the ESC performance assumptions
- further design details of existing vault and future vault leachate drainage, container spacing, collection and monitoring infrastructure

Vault 8 has a vertical concrete dividing wall on its southern edge. The 2011 hydrogeological model assumes that penetrations in this wall, together with a significant increase in the hydraulic conductivity of the concrete as a result of age degradation, will make sure that leachate can flow from Vault 8 into the adjacent Vault 9A and Vault 9. However, LLW Repository Ltd considers it likely that flow through the base of Vault 8, combined with flow through degrading vault walls, will be sufficient to remove the requirement for Vault 8 leachate to be managed via Vaults 9A or 9. Thus these over-spill arrangements will be there as a precaution. In ESC-FI-023 we request further investigations into the performance assumptions used to characterise the behaviour of concrete vault structures. These investigations should be used to inform the repository leachate drainage design and will support the design justification process.

Trench leachate management

Leachate from the trenches is currently managed using the leachate collection infrastructure installed during trench construction. This infrastructure consists of porous basal pipes which penetrate firebreaks, but do not extend the length of the trenches, with a gravity fed outfall or outfalls. The quality and current functionality of the infrastructure is unknown. Leachate height can be monitored across the trenches at over 60 retro-fitted gas probes (LLW Repository Ltd 2011b). This design represents contemporary leachate management practice during the construction of the trenches. Since the installation of the interim capping system LLW Repository Ltd has continued to update and replace the existing infrastructure. Irrespective of these improvements, the current design provision for leachate management and monitoring capability does not meet modern standards.

The 2011 ESC does not present a comprehensive trench leachate management strategy or detail how the leachate collection system and leachate monitoring provision will be maintained before and after final capping. We consider that the ESC would benefit from improved information on the predicted long-term behaviour of trench leachate and also how it will be managed and monitored and the necessary infrastructure maintained.

In ESC-FI-023 we ask LLW Repository to develop a leachate management and monitoring strategy for the trenches. As with the management of the vault leachate, we request that further evidence is developed to support understanding of trench leachate behaviour during and after the period of authorisation and that a leachate management strategy is further developed to support the ESC. In doing this we accept that options for improvements to the basal leachate collection system are likely to be restricted or challenging, but we still expect options for improvement to be considered. The strategy should consider further the pre- and post-final capping trench leachate monitoring requirements and how to provide leachate monitoring requirements over an extended time[9]. This might include, for example, reviewing leachate and gas monitoring and sampling requirements and developing a leachate strategy for the whole period of authorisation as part of the interim trench cap strategy.

Long-term leachate behaviour

After the degradation of the cap, the vault leachate management features are designed to minimise the length of time the waste is in contact with leachate and prevent over topping to the near-surface environment. We are satisfied this design can perform as intended, although we encourage LLW Repository Ltd to continue to develop further understanding of the repository evolution sequence up to the beginning of site disruption.

The design of the future vaults includes a basal granular drainage layer below the basal lining system. The drainage layer comprises, where necessary, 500 mm thick engineered free-draining stone with a permeability of not less than 10^{-4} m s^{-1}. However, engineered granular materials will only be used where granular high permeability geological material is not already present and additional drainage capacity is required. LLW Repository Ltd proposes to construct a horizontally extended drainage layer under the future vaults, with a continuous vertical element on the east and west edge of the vaults. The vertical element provides the linkage between the vault and the basal drainage layer. The vertical element may comprise of natural or engineered granular materials (LLW Repository Ltd 2011b). The company considers that these proposals include significant performance redundancy, with the extent of the engineered basal drainage layer to be determined by the presence of adjacent high permeability granular geologies (Shevelan 2012a).

Vaults 8 and 9 do not include the engineered basal drainage system. Vault 8 has vertical concrete sides extending to the top of the vault, Vault 9 has a concrete annulus extending to the top of the vault with a 1 m high BES liner[10]. Vaults without the basal drainage layer feature will, in part, rely on the ability of the leachate management system to disperse leachate to the adjacent down-gradient vaults to manage leachate and prevent overtopping. However, some element of dispersion may also occur through the side walls of Vaults 8 and 9 following degradation of the engineered features, or if retrofitted with penetrations to aid flow. Vaults which incorporate the basal drainage layer and a 1 m high low permeability side wall will preferentially channel leachate

[9] This requirement is also applicable to gas generation.
[10] The design could be retrofitted to allow lateral leachate dispersion above the BES liner.

to the sides (east and west) into the basal drainage layer. Vaults 9 onwards will also be designed with a southerly wall slightly higher than 1 m to allow hydraulic continuity along Vaults 9 to 14 if required to provide additional drainage capacity, allowing access to the basal drainage layer associated with each vault. As the ESC is further developed and the engineering design subject to further design justification we expect to see increasing understanding and certainty of the conceptualised sequence of leachate flow following the degradation of the cap.

The basal drainage layer will need to effectively disperse leachate when overtopping begins, which is projected to happen after a minimum of 400 years due to the degradation of the capping system. The extent of the required length of performance for the basal drainage layer significantly exceeds the period for which current engineering performance data exists. However, we expect LLW Repository Ltd to further develop its evidence to support the functionality of the basal drainage layer or to otherwise demonstrate that there is significant redundancy in the available drainage. To achieve this we recommend that the company considers carrying out investigations into the long-term performance of the granular materials. Any such investigations need to examine the nature and extent of chemical, biological and physical clogging mechanisms that could happen in saturated and unsaturated conditions. We set out our expectations in ESC-FI-023.

During our review of the 2002 PCSC, we raised an IAF (IAF SDE_004.2) that asked BNFL to demonstrate that either the overtopping drainage system is likely to function as intended at the appropriate time or, if not, that the failure of the system is represented in the scenarios considered in the environmental safety assessment. Despite the overtopping drainage design being different in the 2011 ESC we consider that this issue remains applicable. Outstanding issues from this IAF are now addressed within ESC-FI-023.

Gas collection and dispersion infrastructure

The design of the final engineered cap presented in the 2011 ESC includes a dedicated gas collection and dispersion layer. The design is entirely passive, designed to allow dispersion of collected gas to a centralised vent in the completed dome restoration landform. Before the completion of the restoration profile, gas will vent passively from the exposed front face of the cap. Due to the composition of waste disposed of to the LLWR we accept that gas volumes and rates of production will be far lower than typical landfills receiving industrial and municipal waste (Environment Agency 2010). For this reason we consider that LLW Repository Ltd’s current engineering design intent for no active gas management to be adequate, appropriate and meeting BAT.

The interim trench cap includes gas monitoring capability in the form of gas probes located across much of the interim trench cap. The current design of the final capping over the whole of the repository does not include gas monitoring and sampling capability after the placement of surcharge and profiling materials. Without this infrastructure it will not be possible to monitor the nature and volume of gas generated from the capped waste, confirming assumptions within the 2011 ESC. We ask LLW Repository Ltd to provide a comprehensive gas monitoring and management strategy for both for the trench and vault disposals in ESC-FI-024. The gas management strategy and any associated designs for monitoring infrastructure will need to be developed before the start of cap restoration.

The long-term performance of the gas collection layer in the final cap was not subject to elicitation studies to consider the aging and degradation of the granular materials used. Although we consider the current design does incorporate sufficient performance redundancy, we consider it would benefit from further design justification and optimisation as necessary. In particular we would like to see further consideration of the degradation of the gas collection layer over time and the implications for gas transit through the engineered systems (see ESC-FI-024).

LLW Repository Ltd's repository design concept does not at present include details of the engineered systems that may be necessary to collect gas from within the vault and trench waste bodies and to transfer it to the gas collection layer. Although the predicted trench and vault gas generation rates are low, as part of the design justification process we expect to see demonstration of the adequacy of the design, or proposals for additional infrastructure. This process should consider the potential for the spatial variability of gas generation across the repository.

Engineered capping system

The engineered cap is designed to provide a suitable long-term landform and robust physical cover as well as a low permeability surface barrier, providing adequate containment and isolation of the waste. It is proposed that the final cap will be installed as a succession of strips across the vaults and the adjacent area of the trenches as each vault is filled with waste. The 2011 ESC presents a multi-layer capping design, describing the function of each layer and its design objectives. We consider that the design and identified functionality of each cap layer is good practice for a near-surface repository. We consider that the proposed cap represents an optimised solution, although before construction we expect to see further detailed evidence to support its assumed performance.

In this section we report on our assessment of the ability of the engineered cap to provide the main functional objectives of resilience to:

- settlement
- infiltration
- instability and erosion
- intrusion (human and biological)

Repository cap settlement

An engineered capping system needs to withstand or accommodate the waste settlement it might reasonably experience to achieve the environmental safety objectives attributed to it.

LLW Repository Ltd substantiates the 2011 ESC cap design using a theoretical maximum settlement to demonstrate that this could be withstood without significantly affecting the functionality and performance of the cap. The company uses a combination of geotechnical assessments and output from the near field Generalised Repository Model (GRM)[11] to estimate the assessed settlement of the cap (Tonks 2011). Cap resilience to settlement is then assessed based on the settlement potential of a single waste container stack and its interaction with adjacent stacks.

This assessment was limited in a number of ways and LLW Repository Ltd has identified the need to provide further assessment and validation of the cap's resilience to settlement to support the 2011 ESC prior to construction. This need for additional work was further confirmed as a result of container condition and settlement investigations (Jefferies 2012, 2013a), the scope of which is detailed in Shaw (2013). In particular, we consider that further work is needed to consider in more detail the timing and manner of potential settlement and the potential effects of cap settlement on individual cap layers and the cap as a whole.

We ask LLW Repository Ltd to identify and quantify the impact of a wide range of realistic settlement scenarios on the safety functions of the cap in ESC-FI-027, taking into account our review findings and the container condition and settlement work carried out since submission of the 2011 ESC. Before construction of the final cap this work will need to address important questions such as the ability of the cap to withstand potential waste settlement, and therefore the ability to stack waste higher in the vaults, to confirm the adequacy of the final detailed cap design. In response to FIs ESC-FI-001 and ESC-FI-027 we expect to see evidence supporting the final design of the cap, taking into account the maximum assessed settlement potential and cap resilience.

Trench settlement

Because of a different waste form and age, the settlement of the trench waste will differ in nature and magnitude from that of the vault waste. The 2011 ESC sought to characterise the residual settlement potential of the trench waste at the point that construction of the final cap begins.

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[11] GRM is a computer programme that models the chemical evolution of the near field and the transport of contaminants in saturated media.

Because of the extended time since the trench waste was emplaced, LLW Repository Ltd's use of modelling and landfill settlement assessment provides an appropriate way of quantifying the nature and magnitude of bulk settlement and we consider represents best practice. The presence of a substantial thickness of consolidated profiling material associated with the interim trench cap will significantly reduce the effect of trench waste settlement on the final cap. The 2011 ESC concludes that the majority of bulk waste settlement has already occurred, and we agree.

LLW Repository Ltd plans to place surcharge material over the trenches before placement of the final cap; the 2011 ESC does not describe the objective of the surcharging. We queried this matter in ESC-TQ-INF-007 and LLW Repository Ltd responded that surcharging would maximise settlement of the trenches before the placement of final capping. We expect the extent and period of surcharging to be subject to ongoing monitoring to confirm its effectiveness, with sufficient flexibility being built into the surcharging process to ensure future settlement potential is minimised. LLW Repository Ltd proposes that measured outputs from the first section of the final cap will validate assessments of cap settlement behaviour and enable future settlement assessments to be improved.

We recommend that prior to construction of the final engineered cap, LLW Repository Ltd ensures, through monitoring, that waste settlement achieved through the application of surcharging provides evidence that any remaining potential for waste settlement is consistent with assumptions made within the 2011 ESC (**Recommendation O&E27**).

The potential for further trench settlement remains uncertain. Because of the substantial thickness of waste and profiling and capping material, together with the use of surcharging in advance of cap placement, we are satisfied that this uncertainty can be adequately managed by the proposed capping strategy.

We conclude that LLW Repository Ltd has characterised the nature and magnitude of trench settlement to a sufficient extent to gain confidence that the proposed surcharging programme will adequately mitigate the effects of settlement on the final cap.

Vault settlement

Cement grout is used to fill void spaces in ISO freight containers before the containers are emplaced in the vaults. Grouting consolidates the waste within the container, as well as reducing voidage. It also strengthens the waste package (LLW Repository Ltd 2011b). As a result of the strength and predicted lifespan of the waste package, LLW Repository Ltd has taken the view that there will be no significant load-related settlement before or immediately after placement of the final engineered cap as a result of the structural integrity of the ISO freight container. After the failure of ISO freight container integrity, load will be transferred to the grouted waste form. The company has sought to characterise the way the waste containers will degrade and, through examining constituents of the waste form, to identify what mechanisms might affect cap settlement in the 2011 ESC (Tonks 2011).

Our review has covered the outcomes of LLW Repository Ltd's container condition investigation (see Section 2.2.3 and Environment Agency 2015j) and of its wider assessment of the vault cap. The following aspects are included, all of which have relevance to the 2011 ESC:

- settlement timing, magnitude and its significance for the performance of the engineered final cap
- ullage at the top of containers and the implications for settlement
- the need for limitation of maximum stack height and changes to the restoration profile
- the presence of non-standard containers and container types and the significance on repository performance
- the significance of waste types and waste packaging arrangements for creating container void space

LLW Repository Ltd considers that the ISO freight containers will provide both containment and structural integrity throughout the period of authorisation. LLW Repository Ltd assumes that after the end of the period of authorisation, at the commencement of coastal erosion, corrosion of the

ISO freight containers will be advanced. No quantitative credit for the longevity of the containers is made in the assessment calculations after the end of the period of authorisation. Degradation of the structural elements of the containers is likely to determine the initial onset of settlement of the vault waste. LLW Repository Ltd concludes that 'none of the issues identified with existing voidage in Vault 8 are likely to impact significantly on Vault 8 performance, either during the period of authorisation or in the longer term. Consequently, there is no requirement for any immediate ‘remedial’ works to control existing voidage in Vault 8' (Jefferies 2013a). We agree that the findings of the vault container condition investigations do not significantly change the predicted Vault 8 performance; however, the outcomes and finding of the investigations need to be appropriately investigated and integrated into the engineered cap design and the near field waste form behaviour.

Small et al (2011) discuss the nature and quantity of waste placed in the Vault 8 containers. A normal distribution of grout to waste ratio is seen, with a significant number of containers in Vault 8 which, according to calculations, have less than 40% by volume of grout. This differs from the average grout to waste ratio used in the 2011 ESC for stack settlement potential. We raised a TQ that sought clarification of the consequence of the lower grout to waste ratios than those identified in the 2011 ESC (ESC-TQ-INF-006). A satisfactory response was received. However, we consider there remains a need to consider whether grout to waste ratios need to be maintained at any particular level and in what circumstances, for example relating to the types of waste material being grouted or the total potential voidage within the stack to which that container is disposed. Consideration should be given to maintaining the stated safety objectives of the grout (containment, waste stability, chemical conditioning and radioactive gas mitigation). To help optimise and understand the grout to waste ratio, the company has implemented waste packaging and recording changes with waste consignors. These changes will help ensure that the grout to waste ratio is optimised and packages are subject to appropriate emplacement strategies.

We consider that LLW Repository Ltd has carried out a comprehensive programme of investigation into container condition and settlement potential (Jefferies 2012, 2013a). We regard LLW Repository Ltd's forward programme in this area as suitable for continuing assessment of settlement in the vaults and investigation of how the effects of settlement can be mitigated. We ask the company to continue its container condition investigations and to integrate the findings into the cap design and optimisation process in ESC-FI-001 and ESC-FI-027.

Non-standard containers and disposals

Vault 8 contains a number of non-standard disposals which include variants of the standard ISO freight container design, containers that are grouted in place, items too large to fit into ISO freight containers and other items that have been directly grouted into place within the vault. The 2011 ESC did not present an assessment of the significance of these non-standard disposals. We therefore raised IRFs ESC-RO-INF-003 and ESC-RO-INF-003b which sought clarification of the nature and extent of non-standard disposals. A response was provided and this is discussed further in Environment Agency (2015c). LLW Repository Ltd has also assessed the settlement potential of non-standard disposals within its wider assessment of container condition and settlement potential (Jefferies 2012), considering disposal locations. These investigations demonstrated that the presence of non-standard disposals may lead to changes to the design detail of the engineered cap, but do not affect the design of the cap overall or its ability to meet performance requirements.

We conclude that the extent and potential impact on settlement of non-standard disposals has been appropriately characterised and considered within the cap design process**.** We ask LLW Repository Ltd to carry out further assessment of the potential impact of Vault 8 waste settlement on the final cap in ESC-FI-001 and ESC-FI-027. This assessment should take account of the location and extent of non-standard disposals.

Container ullage

LLW Repository Ltd has surveyed the extent and distribution of ullage space between the underside of the ISO freight container lid and the top of the grouted waste form within exposed Vault 8 containers. Most of the surveyed containers were at the top of waste stacks, thus allowing easy access for the survey. To assess the ullage within containers that have been held lower down a waste stack, LLW Repository Ltd has surveyed a series of stacks that had previously been transferred from Vault 8 to Vault 9 (Jefferies 2012). The ullage space observed in the top of some containers could be the result either of failure to fill the container completely with grout, grout softening, or of later settlement within an initially full container (Jefferies 2012). The extent of ullage within containers and its distribution is important as it affects cap settlement potential and therefore the final design of the cap and the ability to higher stack containers within the vaults.

Jefferies (2012) found that the ullage voidage was far more prevalent and significant than could be attributed simply to softening of the grout. The maximum observed ullage depth was 320 mm for one of the container types (type 2032 containers). The largest average ullage depth for a single container type was 109 mm, for type 2895 containers.

LLW Repository Ltd considers it is most likely that this ullage results from voidage in the waste that is inaccessible during grouting. The ullage depth does not appear to be directly related to waste type (Jefferies 2012). Grout is poured into the waste and it is believed that the weight of the grout and the waste itself subsequently causes settlement into the voidage that was not initially filled by the grout. This process is thought to occur shortly after grouting.

To address these findings LLW Repository Ltd has changed its grout pouring operational instructions to make sure that the ullage space in ISO freight containers is minimised before transport to the vault. Periods of settlement are allowed and the grout topped up as necessary until it is confirmed that the container is filled to within a defined tolerance. This approach has been formalised within company procedures. We are reassured that appropriate measures have been taken to ensure that ullage space is minimised during the grouting process (Jefferies 2013a). As part of its future work programme and asset care, LLW Repository Ltd plans to continue to monitor the ullage space within containers stored and disposed in Vault 8 and 9 to gauge whether any further change is happening and to gather further data to support assessments.

We are satisfied that LLW Repository Ltd has gathered sufficient information on container ullage to support cap settlement assessments and therefore design, and that design changes and controls on maximum container stack height can ensure settlement is appropriately limited and mitigated (ESC-FI-001). However, we support the fact that the company plans to continue to gather further information to support settlement assessment and increase understanding.

Characterisation of settlement potential

As part of the container condition programme, Penfold et al. (2013) investigated the implications of voidage in Vault 8 for settlement. The maximum potential for settlement estimated for an entire container stack is 2 to 2.25 m. The maximum potential for differential settlement between adjacent stacks will therefore be 2.25 m, although in most places the potential for differential settlement will be in the range of 0 to 1.5 m (Penfold et al. 2013). Penfold et al. (2013) has identified those areas of Vault 8 where settlement could affect the integrity of the cap. However, it is not clear whether this assessment fully takes into account the levels of uncertainty associated with the inventory records and the resulting waste mass.

Because of the uncertainty associated with the past inventory information and the need to use indirect assessment approaches to identify potential void fractions, the uncertainty in characterising the possible void space in past containers is high. We consider that the void space assessments based on inventory information should be used only as an indicator of settlement potential. In ESC-FI-001 we set out our expectations for LLW Repository Ltd to develop and demonstrate a conservative and precautionary engineering approach to the container stacking arrangement and final cap design that takes account of the uncertainty in the amount and distribution of waste void space.

Because of heterogeneity in the distribution of waste void space and the rate of container degradation, it is reasonable to assume that settlement will differ between stacks both in its timing and the eventual quantity. The design of the cap therefore needs to take account of this behaviour. We consider that the investigation of waste voidage has provided good indicative information about settlement; this is a significant advance, but there are still uncertainties in the magnitude of settlement potential both at a container and stack scale. We will require these uncertainties to be reflected in the maximum container stack height and the mitigation of the effects of settlement through the design of the engineered cap. We consider that LLW Repository Ltd can make the design more robust by establishing better links between uncertainties in container performance and optimisation of cap performance. We set out our expectations for future investigations in ESC-FI-001, including an expectation for LLW Repository Ltd to further substantiate the design of the final cap taking full account of total and differential waste settlement potential and uncertainties associated with it. Despite the uncertainties remaining, we consider that the assessment of Penfold et al. (2013) represents a major improvement over the characterisation of settlement potential in the 2011 ESC (Tonks 2011). We expect ongoing observations of container condition to inform future assessments.

Cap resilience to infiltration

Infiltration through the final cap is an important performance indicator in the 2011 ESC due to its effect on the rate of generation of leachate and effects on waste degradation and thus environmental impacts via the groundwater and gas pathways. During the period of authorisation, LLW Repository Ltd will manage leachate levels within the vaults, thereby decoupling the cap performance from basal discharge (LLW Repository Ltd 2011b). However, it is important for LLW Repository Ltd to manage infiltration into the trenches, and maximise trench leachate collection capability, in order to manage trench leachate levels throughout the period of authorisation. For both the vaults and trenches, LLW Repository Ltd makes the case that the final cap design presented in the 2011 ESC represents BAT for the prevention of infiltration.

The 2011 ESC indicates that, after the period of authorisation, the final engineered cap will degrade before the vault basal lining system, resulting in an inflow into the vault that exceeds the discharge via the base. LLW Repository Ltd's view is based on the degradation of performance of the final engineered cap viewed as a whole. The presented degradation corresponds to realistic in situ degradation rates for engineered capping materials such as cover erosion and desiccation of the low permeability layer. We are therefore satisfied that the assessed degradation and inflow rates through the cap are adequately bounded. However, we consider the company’s assessment does not make it clear how it has taken into account performance reductions associated with a wider range of possible localised failure mechanisms, principally differential settlement. Although any such localised failures are unlikely to lead to significantly greater inflow through the cap overall, they could alter the location of flows, potentially affecting the ability of the leachate management system to work effectively. Within FI-ESC-026 and ESC-FI-027 we ask LLW Repository Ltd to consider this issue further.

The 2011 ESC does not take account of the presence of a significant thickness of engineered profiling material in the elicitation of cap hydraulic conductivity. Profiling material will exhibit low hydraulic conductivity properties throughout the assessment period and thus slow down the rate and volume of leakage into the waste throughout the lifetime of the cap. This further increases our confidence in the conservative nature of the company’s assessment of infiltration. We recommend that LLW Repository Ltd gives careful consideration to any increased performance benefits from the profiling materials, including how the profiling material will affect leakage through the cap (**Recommendation O&E28**).

The 2011 ESC focused on the design and functioning of engineered barriers. One of the outcomes of the container condition review (Jefferies 2013a) has been the identification of the role in the provision of safety played by engineered fills and engineered profiling materials. The 2011 ESC (LLW Repository 2011b) did not identify or assess the role of these materials in provision of safety objectives or take account of specific design requirements needed for these materials. We therefore recommend that updates of the ESC consider engineering profiling and fill materials as part of the engineered safety systems (**Recommendation O&E29**). Profiling and fill materials may therefore need to be subject to performance assessment and appropriate construction quality assurance.

Cap resilience to instability and erosion

Maintenance of geotechnical stability and minimisation of erosion of the final capping system will be met by both the restoration shape and the capping system design and is passive in nature. For near-surface disposal facilities, the capping system should be designed to maintain its integrity for as long as possible, over potentially 100s or even 1000s of years.

In the long-term the erosion and instability of the cap may be influenced by its final restoration design, cover system and vegetation choice for its surface. Although these details can be finalised closer to the point of construction, we recommend that LLW Repository Ltd should consider further investigations into and optimisation of the final design of the cap surface, including cover system and vegetation, to minimise the risks of erosion, whilst considering conservation requirements, the coastal location, possible future climatic change and planning requirements (**Recommendation O&E30**).

Erosion and instability may also be influenced by the behaviour of surface water and we consider that during development of the detailed design in the run up to construction, the design of the final cap would benefit from further consideration of surface water management infrastructure to manage a reasonable range of expected rainfall events, sustainable drainage systems and surface water velocity control. LLW Repository Ltd should consider how it will measure cap erosion rates during the period of authorisation to confirm assumptions, inform the ESC and identify any necessary remedial action.

The single dome restoration cap design presented in the 2011 ESC includes a minimum slope angle of 4%, which is consistent with landfill best practice. However, LLW Repository Ltd proposes steeper slopes at the edges of the cap, to a maximum of 20% at the edges (outside the footprint of the waste)[12]. To gain confidence that these steeper slopes are appropriate, we raised a TQ (ESC-TQ-SUE-023) that asked LLW Repository Ltd to demonstrate that all elements of the proposed restoration cap will remain stable in the long-term (for example, until disruption of the site by coastal erosion). We asked LLW Repository Ltd to assess the stability of a typical 10% side slope element and a worst-case side slope element (assumed to be 20%).

In response, LLW Repository Ltd assessed the cap stability before and after cap degradation and after the removal of the slope toe as a result of an unforeseen erosion event. The company demonstrated that the risk of slope instability is minimal (URS 2012). The factor of safety against slope instability is greater than 1.3 and this is considered adequate in the long-term.

We consider that LLW Repository Ltd's slope stability assessments are realistic and appropriate. However, we consider that the slopes at the edge of the cap would benefit from reduction if possible, and optimised, talking other factors into account. This may be challenging given the restrictions in place due to the boundaries of the site. In Recommendation O&E16 we ask LLW Repository Ltd to consider the feasibility of reducing the steepest elements of the cap slope.

Resistance to intrusion (human and bio-intrusion)

An important element of the cap's function is to provide a robust and substantial physical barrier between the waste and the external environment over an extended timeframe. The engineered cap design has a thickness of 3 m, which is in addition to a substantial thickness of profiling material above the waste (minimum thickness 1 m). We consider that LLW Repository Ltd has adequately demonstrated that the cap and profiling material can provide isolation of the waste in the long-term and adequate shielding from direct radiation doses.

In our review of the 2002 ESCs (BNFL 2002c) we noted that BNFL needed to substantiate the assertion that the bio-intrusion layer in the proposed final cap design will provide an obstruction barrier to burrowing animals and deter roots from penetrating into deeper layers (IAF SDE_007.3). In response, LLW Repository Ltd provided support for the design by comparison to landfill engineering (Thorne 2008). Although we accept that the cap design is generally appropriate, we consider that in the run up to construction there remains a need to further substantiate the cap's resilience to intrusion and the functionality of the bio-intrusion layer, taking into account site-specific data where possible. Our expectations for this work are included in ESC-FI-027.

[12] See drawing Long Sections B-B (D-02) and Plan and Typical Cross-Section (Schematic) (D-01) (LLW Repository Ltd 2011b).

Cut-off wall design

Resulting from the optimisation process, LLW Repository Ltd expanded both the function and extent of the perimeter cut-off wall with the aim of minimising groundwater ingress into the waste mass, minimising contact of leachate with the waste and directing leachate downwards away from the waste to avoid discharges to the near-surface environment. LLW Repository Ltd intends to construct a cut-off wall around the whole disposal area to a depth of 2 m below the base of the waste mass. We consider that the proposed design, material specification and elicited performance of the cut-off wall are appropriate. Evidence supporting the design builds on performance monitoring carried out on the existing cut-off wall to the north and east of the trenches. However, we recommend that future updates of the ESC more clearly describe the role of the cut-off wall, in conjunction with the basal drainage layer and in-situ granular material in reducing the extent and mitigating the consequences of overtopping (**Recommendation O&E31**).

Because of the heterogeneous nature of the shallow geology below the future vaults, we consider it essential that the geologies between the existing repository and the cut-off wall are taken account of in the design of the cut-off wall. This may mean that the depth of the cut-off wall will correspond to the local geological conditions rather than the base of the vaults. We also consider it important that locally derived site investigation and groundwater monitoring information is used to inform and validate the ongoing performance of the installed cut-off wall. The annulus between the cut-off wall and the edge of future vaults also plays an important role in the prevention of leachate overtopping. It is therefore important that the construction of the cut-off wall takes into account its proximity to the vault side liner.

To validate the ongoing performance of the cut-off wall in limiting groundwater ingress into the vaults, we recommend that LLW Repository Ltd considers inclusion of monitoring infrastructure between the cut-off wall and the vault (**Recommendation O&E32**).

Vault wall and side liner design

LLW Repository Ltd has changed the design of the side-liner in the future vaults to allow overtopping of leachate once the cap has substantially degraded and water is entering the waste mass. The side-liner will consist of a 1 m vertical 'lip' extension of the basal lining system. Either engineered granular material or in-situ granular geological material will provide a drainage pathway between the vault and the basal drainage layer should leachate overtop the vault side-liner.

Overall we are satisfied with the conceptual design of the vault walls and side-liner design and that it can meet the performance requirements of the ESC. However, we consider that the design and its environmental safety objectives could have been more clearly described within the 2011 ESC. In our review of the Safety Case Management documentation (Environment Agency 2015b) we identify the need to clarify and attribute environmental safety objectives to different elements of the repository engineered systems. Also, as with the granular basal drainage layer, we consider that further substantiation of the vertical element of the granular drainage design may be required before construction. In particular this should take into account the potential for localised clogging of the material over time, but also the ability of the granular material to provide a structural element, for example the lateral containment of the repository waste. In ESC-FI-023 we ask the company to carry out further investigations into the long-term behaviour of granular drainage systems within the repository design, prior to construction.

Concrete slab performance

The design of both Vault 8[13] and the future vaults includes a reinforced concrete basal slab on which waste is placed. The function of the concrete slab is mainly to provide a structural surface on which the stacked waste containers are placed; however, the 2011 ESC also gives credit to the containment capability of the slab as part of the engineered containment system. We sought clarification of the significance of this containment function in ESC-TQ-SUE-024.

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[13] The Vault 8 basal slab incorporates under-slab drainage pipes and is different to later vault slabs.

In response, LLW Repository Ltd provided further evidence that the reinforced concrete basal slab, in conjunction with the membrane and BES materials in the base liner, can provide effective containment over extended periods (Shevelan 2012b). LLW Repository Ltd demonstrated that both the presence of vertical joints within the concrete slab and the degradation of the concrete slab had been appropriately characterised in the elicitation process. Although the repository scale engineering feature model includes the properties of the concrete slab, LLW Repository Ltd does not consider the slab to be a significant component in the basal containment system.

We also sought confirmation that the reinforced concrete basal slab could provide the necessary foundation for the proposed waste stacking arrangement and heights. LLW Repository Ltd provided further evidence that, when loaded to the maximum container stack height and loaded with the cap restoration material, the concrete slab would maintain its integrity.

We consider that LLW Repository Ltd has adequately demonstrated and provided evidence that the reinforced concrete basal slab will perform as designed.

2.3.12. Seismic Assessment

The 2002 PCSC included a seismic assessment of the 2002 restoration landform design. The repository restoration design has since been subject to changes in its layout and slope design. We therefore sought confirmation that the 2011 ESC cap design, in particular the side slopes, would remain seismically stable (see ESC-TQ-SUE-026). In response, LLW Repository Ltd presented further information to demonstrate that the single dome restoration design and associated capping slopes meet relevant seismic performance requirements. We accept this demonstration.

2.3.13. Engineering design for the period of institutional control

The period of authorisation includes the operational period, which LLW Repository estimates will continue up to 2080 AD in the case of the RDA or 2130 AD in the case of the EDA, and a subsequent period of institutional control. Institutional control is anticipated to last for a minimum of around 100 years following completion of disposals and final capping (and a maximum of around 300 years). During this period, the functioning of the repository will need to be monitored and maintained.

LLW Repository Ltd discusses potential strategies for the institutional control period in Penfold et al. (2010). Throughout the institutional control period it is important that repository infrastructure, including monitoring equipment, can be maintained or replaced as necessary. We recommend that, before construction of the final cap or future vaults, LLW Repository Ltd gives further consideration to requirements for long-term monitoring and maintenance of repository infrastructure. This will ensure that the design fully takes account of the need for long-term maintenance throughout the institutional control period. The design should, as far as possible, ensure that no actions are taken that will preclude long-term maintenance or replacement of infrastructure required throughout the period of institutional control (**Recommendation O&E33**).

2.3.14. Extended Disposal Area

LLW Repository Ltd presents the engineering design of the EDA separately from that of the RDA (LLW Repository Ltd 2011h). The design of the EDA engineering is near-identical to that of the RDA, although it covers a larger footprint. Most of our comments on the RDA engineering are also relevant to the EDA. We expect that any learning from the development, construction and operation of the RDA will be used, along with continued optimisation and advances in engineering design, to improve the design of later vaults.

Development and operation of the EDA will delay the installation of a final cap over a small area of the trenches according to the current plans. The current trench cap management strategy does not include the provision of a replacement for the interim trench cap and assumes the current interim trench cap will remain in place until the placement of the final engineered cap (Paulley et al. 2012). LLW Repository Ltd may need to review this to take account of an extended exposure period and degradation over time of the interim trench cap.

The additional EDA vaults (Vaults 15 to 20) lie adjacent to the southern edge of the trenches and RDA vaults. It is important that the functionality of the existing basal trench leachate collection and monitoring infrastructure is not compromised by the construction of these vaults, or adequate replacements are provided as part of the design.

As Vaults 15 to 20 are progressively constructed the total rainwater catchment of the vaults will continue to increase, potentially leading to the collection of increasing volumes of leachate resulting from infiltration. The bases of these vaults also become progressively shallower. These factors increase the importance of effective leachate collection, management and dispersion during and after the period of authorisation, to prevent leachate overtopping to the surface environment. As part of the EDA design development and justification process, we will require confirmation that the accumulation of leachate can be limited sufficiently to prevent overtopping along the southern edge of the EDA vaults (see ESC-FI-023).

The 2011 ESC has presented an adequate engineering design for the EDA. It is not anticipated that the EDA vaults will be constructed for a number of decades, if they are required at all. Therefore, at this point in time, we do not expect to see detailed engineering designs. However, if EDA vaults are constructed in the future, we will expect their designs to be fully developed and to take account of learning from the construction, operation, capping and monitoring of previous vaults.

3. Meeting our requirements

LLW Repository Ltd submitted the 2011 ESC as required by Schedule 9 Requirement 6 of the current LLWR environmental permit. This required the operator to 'update the Environmental Safety Case(s) for the site covering the period up to withdrawal of control and thereafter'.

We define an ESC as, 'the collection of arguments, provided by the developer or operator of a disposal facility, that seeks to demonstrate that the required standard of environmental safety is achieved' (Environment Agency et al. 2009). In this section we provide a summary of our review of the optimisation and engineering sections of the 2011 ESC and assess whether relevant parts of the GRA have been met.

GRA Principle 2 and Requirement R8 specifically relate to optimisation. There are no requirements specifically relating to engineering; however, several other GRA principles and requirements are relevant to the LLWR engineering design and its optimisation.

3.1. Principle 2: Optimisation (as low as reasonably achievable) and Requirement R8: Optimisation

GRA Principle 2 states that 'Solid radioactive waste shall be disposed of in such a way that the radiological risks to individual members of the public and the population as a whole 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 radiological risks to other living organisms and any non-radiological hazards' (GRA paragraph 4.4.1).

Requirement R8 states that '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 make sure radiological risks to members of the public, both during the period of authorisation and afterwards, are as low as reasonable achievable (ALARA), taking into account economic and societal factors' (GRA paragraph 6.3.56).

LLW Repository Ltd has carried out a wide range of optimisation studies prior to and during the development of the 2011 ESC. LLW Repository Ltd uses the output from these studies to demonstrate that the LLWR and the SDP are optimised with respect to:

- management of past disposals
- management of future disposals
- pre- and post-closure engineering design
- operational and post-closure management controls

LLW Repository Ltd has demonstrated that past disposals to the facility may currently be regarded as optimised and that retrieval of all or part of the waste is unlikely to be optimal. However, LLW Repository Ltd acknowledges that the interim trench cap and leachate management system requires improvements such that it continues to represent an optimised design through to the point of final capping. To this end, at the time of writing, LLW Repository Ltd is completing further optimisation studies, with a view to completing necessary trench cap improvements in the short-term. The company also needs to carry out work to demonstrate that items currently stored in Vaults 8 and 9 will be disposed of in accordance with BAT and plans have been put in place for this work.

LLW Repository Ltd has identified a range of improvements to the WAC and operational procedures that we consider are capable of achieving the optimisation objectives of the ESC and are suitable for managing future disposals and the site until the end of the period of authorisation. We consider that the SDP has been optimised at an appropriate level. However, before construction of the final cap or further vaults we require a substantial further programme of work to take account of material performance, detailed design aspects and to further substantiate the performance of various engineering components both individually and as an engineered system as a whole. This may involve further detailed optimisation of the design. We have asked LLW

Repository Ltd for a comprehensive forward engineering programme and have set out our requirements in a number of FIs (see Appendix 3). LLW Repository Ltd has already put a programme of work in place which we will review in the run up to any further development.

We consider that LLW Repository Ltd has provided sound arguments and reasoning for all the main optioneering decisions and, in that respect, has made an optimisation case that meets Principle 2 and Requirement R8 of the GRA. However, the optimisation process itself was not as clear or as well documented as it could have been, making review challenging. In the future additional effort should be placed into clearly documenting the iterative optimisation process in such a way that it can be readily traced and linked to the wider repository concept.

We consider that LLW Repository Ltd has produced a SDP that will allow the design to be realised in practical terms, although LLW Repository Ltd will need to review the SDP regularly to make sure that it remains appropriate and optimised. The ESC has been informed by sound arguments and reasoning for all the main optioneering decisions and we consider that the requirements of the GRA for optimisation have been met.

3.2. Requirements R5, R6 and R7: protection of human health against radiological hazards

GRA Requirements R5 (dose constraints during the period of authorisation), R6 (risk guidance level after the period of authorisation) and R7 (human intrusion after the period of authorisation) set out our constraints and guidance levels that we consider protective of human health from radiological hazards. We consider that LLW Repository Ltd has applied these constraints and guidance levels appropriately in demonstrating that the repository will protect human health during the period of authorisation and afterwards (Environment Agency 2015e).

In its optimisation process LLW Repository Ltd needs to demonstrate that the options it selects lead to radiation doses and risks that take account of these constraints and guidance levels and are ALARA. As discussed above, we have concluded that, in the context of the current stage of development of the LLWR and the ESC, LLW Repository Ltd has met GRA Principle 2 and Requirement R8 through the optimisation and assessment studies supporting the 2011 ESC.

The environmental safety functions provided by the engineered systems are important in ensuring that the facility will meet GRA Requirements R5, R6 and R7. For example, the final engineered cap contains layers to facilitate the dispersion of gas, reduce infiltration (and hence the generation of leachate) and minimise the likelihood of human intrusion. We are satisfied that LLW Repository Ltd has suitably addressed these requirements. However, we have identified a number of areas where further detailed design development and substantiation is required and ongoing. We discuss these areas in Section 2 and, where necessary, we have raised recommendations or FIs to outline our requirements (See Appendices 2 and 3 respectively). In particular we note the need for further work to be completed on the potential effects of container and waste settlement on the integrity of the final cap. LLW Repository Ltd is progressing work in this area to demonstrate that waste stacking and cap design will meet performance requirements and we have raised FIs (ESC-FI-001 and ESC-FI-027) outlining our expectations for this work.

Taking into account the need for further detailed design work before the beginning of construction of the cap or future vaults, we conclude that the 2011 ESC has presented proposals for a repository that meet the requirements of R5, R6 and R7.

3.3. Principle 3: Level of protection against non-radiological hazards at the time of disposal and in the future and Requirement R10: Protection against non-radiological hazards

Principle 3 of the GRA states that 'Solid radioactive waste shall be disposed of in such a way that the level of protection provided to people and the environment against any non-radiological hazards of the waste both at the time of disposal and in the future is consistent with that provided by the national standard at the time of disposal for waste that present a non-radiological but not a radiological hazard' (GRA paragraph 4.5.1).

The GRA goes on to state in Requirement R10 that 'The developer/operator of a disposal facility for solid radioactive waste should demonstrate that the disposal system provides adequate protection against non-radiological hazards' (GRA paragraph 6.4.1). Our review of the repository engineering design sought to confirm that it provides a level of protection against non-radiological hazards that is no less stringent than nationally accepted engineering design standards for hazardous waste landfills. LLW Repository Ltd has done this in the 2011 ESC by comparing the level of containment and system design to that set out in the Landfill Directive to demonstrate that the engineering design is capable of providing an equivalent and appropriate level of protection against non-radiological hazards.

We consider that the 2011 ESC adequately takes into account both radiological and non-radiological design objectives in an appropriate manner and presents a repository design that will provide adequate protection against both radiological and non-radiological hazards over the lifetime of the repository. The interim cap over the trench disposals has been identified by the company and us as an area potentially requiring improvement. As discussed elsewhere, work is ongoing to establish improvements to the trench cap that will represent BAT through to the point of final capping and also to achieve a level of protection equivalent to that of a historical non-radioactive landfill.

3.4. Requirement R11: Site investigation

GRA Requirement R11 states that 'The developer/operator of a disposal facility for solid radioactive waste should carry out a programme of site investigation and site characterisation to provide information for the environmental safety case and to support facility design and construction' (GRA paragraph 6.4.6). We consider that LLW Repository Ltd has appropriately used information from site investigations to inform the engineering concept and design. We will, however, expect LLW Repository Ltd to continue to develop and optimise the detail of the engineering design taking full account of site-specific data and characteristics. Additionally, in our review we have noted the importance of ongoing site and engineering investigation and monitoring to inform the engineering design and confirm performance. We have outlined our expectations in this area within recommendations and FIs (see Appendices 2 and 3).

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

Requirement R12 of the GRA states that 'The developer/operator of a disposal facility for solid radioactive waste should make sure that the site is used and the facility is designed, constructed, operated and capable of closure so as to avoid unacceptable effects on the performance of the disposal system' (GRA paragraph 6.4.16).

Overall we have concluded that the proposed engineering design and proposals for its construction and operation are consistent with Requirement 12 of the GRA. We are satisfied that the design can achieve acceptable environmental performance. However, as noted in Section 2 we have identified a number of areas where we and LLW Repository Ltd see the need for further more detailed design development, substantiation and optimisation before construction. This work is ongoing.

For example, container condition surveys identified several mechanisms that could influence the long-term performance of the disposal system due to settlement (Jefferies 2012). As a result LLW Repository Ltd has instigated a programme of work to gather further information, assess settlement potential and implement any necessary design or operational improvements prior to construction of the final cap (Jefferies 2013a and Shaw 2013). Also, Jefferies (2013a) recognised the potentially detrimental effect of the extended exposure of grouted containers before the placement of the final cap. As a result LLW Repository Ltd has instigated further optimisation and development work to consider ISO freight container design and the overall optimised approach to the protection of waste containers before capping. We have outlined our expectations for these and other areas of work within a number of FIs (see Appendix 3).

We note that there is significant uncertainty in the rate and volume of future radioactive waste disposals to the LLWR. We are satisfied that the proposed phased restoration sequence offers sufficient flexibility to accommodate this uncertainty.

3.6. Other requirements

3.6.1. Use of expert judgement

LLW Repository Ltd's elicitation process used expert judgement to develop a range of engineering performance values. As discussed in our Safety Case Management review report (Environment Agency 2015b), we consider that the use of the elicitation process has met the requirements of paragraphs 7.3.29 to 7.3.30 of the GRA. As the design is subject to continuing development and justification, and the results of the engineering forward programme and engineering monitoring programme become increasingly available, we expect to see a move from the use of elicited data to site or experimentally derived data wherever viable and of benefit.

We consider it important that in future optimisation and engineering work LLW Repository Ltd should improve the recording and presentation of the use of expert judgement in elicitation processes and of supporting information (see ESC-FI-029).

3.6.2. Multiple-function environmental safety approach

The engineering design includes multiple systems that LLW Repository Ltd claims can achieve the required environmental safety objectives. During our review, we requested further clarification and substantiation of the environmental safety functions provided by each part of the system (ESC-RO-ASO-005), which LLW Repository Ltd provided. We consider that, whilst the engineering design meets the requirements of GRA paragraphs 7.3.2 to 7.3.4 on a multiple-function environmental safety approach, LLW Repository Ltd will need to consider whether it can make improvements to the presentation and explanation of its multi-function approach to environmental safety and of the environmental safety function of each part of the system within future updates to the ESC. This issue is discussed further in Environment Agency (2015e).

3.6.3. Engineering good practice

The GRA does not prescribe any specific requirements relating to repository engineering; instead, it allows a developer/operator to develop its own design in response to performance requirements, site conditions and the need for optimisation. In our review, we have assessed whether the engineering design of the LLWR is consistent with engineering good practice, and whether the environmental safety functions and associated performance assumptions are appropriate and substantiated.

Overall we are satisfied that LLW Repository Ltd has demonstrated use of engineering good practice in the majority of areas and has been able to demonstrate an appropriate level of design substantiation at this stage. Where necessary we sought further information and we have made recommendations for further improvements or raised FIs seeking further work necessary to implement a fully substantiated engineering cap and future vault design (see Section 2). LLW Repository Ltd has identified the need for further design work within its forward programmes.

We note that LLW Repository Ltd's current assessment of the performance of the engineered systems is largely based on elicited and modelled information. We consider this position reasonable for the current stage of development of the facility. However, as LLW Repository Ltd develops the design further and as site based evidence of performance becomes available, we will expect it to increasingly use site-derived and material-specific information where available and beneficial to do so. It is important that LLW Repository Ltd sets out a forward programme of work, including an engineering forward programme, which addresses uncertainties within the ESC, such as those associated with potential engineering failure mechanisms and long-term performance of engineered features. LLW Repository Ltd has recognised this need and has established and is developing further a forward programme of work. We set out our expectations for engineering aspects of this programme in ESC-FI-026 and elsewhere.

The engineering design outlined in the 2011 ESC has utilised both current landfill and near-surface repository engineering design principles. The engineering forward programme (Shaw 2013) has identified specific elements of the engineering design that require further investigation and detailed comprehensive work programmes that aim to provide the necessary engineering design justification. We consider this represents engineering good practice.

As design development and construction proceed it is important that effective links are maintained between the design development and justification process and the ESC. We are satisfied that management arrangements are appropriate for this, but LLW Repository Ltd should continue to review the adequacy of arrangements as it moves towards construction.

3.7. Summary

In summary, we consider that LLW Repository Ltd has adequately addressed the parts of the GRA of relevance to optimisation and engineering. The engineering design presented in the 2011 ESC meets regulatory expectations and we consider it suitably optimised.

There are a number of areas, as discussed in Section 2 and summarised in Appendices 2 and 3, where we consider further improvements can continue to be made to make sure the ESC continues to meet the requirements of the GRA. Additionally we note, and LLW Repository Ltd acknowledges, that a forward engineering programme is necessary to further develop and substantiate the 2011 ESC design to the level of detail required for implementation. This work has already been started by LLW Repository Ltd and will be required before construction of the final cap or any subsequent vaults.

4. Conclusions

LLW Repository Ltd submitted the 2011 ESC as required by Schedule 9 Requirement 6 of the current LLWR environmental permit. In the 2011 ESC, LLW Repository Ltd has presented the output of a wide-ranging programme of optimisation studies, which have informed the development of an engineering design and operational practice that is used to underpin the 2011 ESC.

We consider that LLW Repository Ltd has adequately addressed the requirements of our Guidance on Requirements for Authorisation: Near-Surface Disposal Facilities on Land for Solid Radioactive Waste (the GRA) relating to optimisation and engineering. The overall quality of the 2011 ESC submission in the optimisation and engineering subject area is of a high standard. However, we identified a number of areas for continued improvement, as highlighted in this document. These areas are outlined in our recommendations and FIs (see Appendices 2 and 3 respectively). We expect LLW Repository Ltd to demonstrate progress against these.

LLW Repository Ltd used a series of optimisation studies to address questions about the future management of past disposals, criteria for future waste acceptance, engineering design and suitable ways of packaging and conditioning waste for disposal. The company uses the output from these optimisation studies to underpin its decisions on site development.

LLW Repository Ltd investigated the optimisation of the site in light of the potential for coastal disruption after a few 100 to a few 1000 years, for example whether to retrieve certain wastes from the trenches. The company concluded, and we agree, that no further actions are required to meet regulatory objectives. However, it should make sure that actions being taken now do not unnecessarily foreclose future options, for example to retrieve certain waste from the vaults or trenches, or to further protect the facility. We agree with LLW Repository Ltd that there is no apparent way of further optimising the design and operating sequence of the repository to reduce the radiological consequences of its expected disruption by coastal erosion in the long-term.

LLW Repository Ltd uses the output from the 2011 ESC to refine the LLWR waste acceptance criteria and develop a number of emplacement strategies to make sure that disposal practices remain optimal. We consider that the proposed waste acceptance criteria and emplacement strategies provide an effective and practical way of delivering optimised impacts from the radiological properties of the waste, with a clear linkage to environmental safety objectives.

Overall, we conclude that LLW Repository Ltd has adequately optimised the repository in terms of both its design and operation, using appropriate processes. However, the documentation of the evolution of the repository design throughout the optimisation process was in places unclear. This made our scrutiny of the optimisation process challenging. We had to request further clarification on optimisation in several areas, including the proposed operational configuration of vaults, vault sequencing, waste protection and the application of emplacement strategies to waste disposed to, or stored in, Vault 8 and subsequent vaults. LLW Repository Ltd addressed these queries to our satisfaction. Although we conclude that LLW Repository Ltd has presented proposals for an optimised design that are appropriate for the current stage of development of the facility, we note that there is further, more detailed design work to be carried out before construction of the final cap or further vaults begins and that this may involve further detailed optimisation.

To help LLW Repository Ltd meet our expectations for detailed design work and for further optimisation, we have raised a series of FIs. Through our routine interactions and regulatory review points, we will make sure that the optimisation work and design detail is subject to regulatory scrutiny and meets our requirements. We are satisfied that LLW Repository Ltd has or will implement suitable changes to procedures and other management arrangements to allow for ongoing optimisation of disposals and design development.

The 2011 ESC presents a Site Development Plan that sets out LLW Repository Ltd's current view of how the repository will be developed as well as providing the baseline against which all performance modelling and assessment throughout the 2011 ESC was carried out.

In response to our request for further clarification of the nature and extent of further engineering work needed before the beginning of construction LLW Repository Ltd provided an engineering forward programme. This programme has moved many aspects of the engineering design forward and, in conjunction with other requests we have made for future work, provides a sound basis for achieving a suitable repository design to meet the requirements of the GRA.

As a result of work subsequent to the submission of the 2011 ESC, LLW Repository Ltd has identified that the interim trench cap is performing less well than assumed in the 2011 ESC and that some ISO freight containers in Vault 8 are observed to be in a poorer condition than assumed. LLW Repository Ltd has further investigated and assessed these issues and has either implemented operational changes or has been able to demonstrate to our satisfaction that they can be adequately addressed through forward work programmes.

We are satisfied that the engineering design meets the relevant requirements of the GRA and is therefore sufficient to provide adequate protection to people and the environment from further radioactive waste disposals at the LLWR. It provides engineered systems that address the required safety objectives, including isolation and containment of the waste. However, we note that the design must and will continue to evolve. Further, more detailed designs will need to be developed and substantiated before construction, for example building detail around leachate management systems and detailed cap construction. To help achieve this and to help continuously improve and optimise the design we expect this work to make good use of appropriate research and development, site specific materials information and engineering performance monitoring. We have outlined our expectations for required engineering development work in the run up to cap and further vault construction in a series of FIs.

Overall, regarding the topic areas addressed in this report, we consider that LLW Repository Ltd has met the requirements of the GRA and Schedule 9 Requirement 6 of the current LLWR environmental permit through the 2011 ESC and supporting documents. This evidence is of a suitable standard and quality to support an environmental permit decision on future disposals at the site.

5. References

Baker, A., Collier, G., Penfold, J, and Wood, A., 2008. Assessment of Options for Reducing Future Impacts from the LLWR. LLW Repository Ltd Report 10002 LLWR LTP, Issue 1.

Baker, A., 2012. Gas Generation Rate Plots from GRM Calculations. LLW Repository Ltd Technical Memo LLWR06488/06/10/01.

Baker, A. and Shevelan, J., 2012. Response to IRF ESC-TQ-INF-018: Trench Cap Leakage. LLW Repository Ltd Technical Memo LLWR/ESC/Mem(12)153.

Baker, A., 2013. Response to Issue Resolution Form ESC-RO-ASO-005: Safety Functions. LLW Repository Ltd Technical Memo LLWR/ESC/Mem(13)201.

Bloomer, S., McGrath, R., Lutman, E., Beadle, I., Pacey, N., Reeves, N., Haigh, T.J., Walker, L., Major, R., Marshall, S. and Conn, J., 2009. The Low Level Waste Repository. Selective Retrievals. LLW Repository Ltd Report LLWRP 675, 15360/TR/0001 Issue 03, August 2009.

BNFL, 2002a. Drigg Operational Environmental Safety Case. September 2002.

BNFL, 2002b. Drigg Post-closure Safety Case: Overview Report. September 2002.

BNFL, 2002c. Drigg Post-Closure Safety Case: Site Development Plan. September 2002.

BNFL, 2002d. Drigg Post-Closure Safety Case: Engineering Performance Assessment. September 2002.

BNFL, 2007. 2007 Annual Performance Assessment of the Interim Cap and Cut-off Wall at the LLWR Trenches. BNFL Report 51905150-002-181-Rep-002-A3.

Champion, J., 2012. Vaults 8 and 9 - Estimated Activity of Authorised Discharges. LLW Repository Ltd Report RP/3409246/PROJ/00261/A, 24 October 2012.

Defra, DTI and Devolved Administrations. 2007. Policy for Long-term Management of Solid Low Level Radioactive Waste in the United Kingdom.

Egan, M., 2011a. Optimisation in Relation to Possible Future Intervention. LLW Repository Ltd Report LLWR/ESC/R(11)10044, November 2011.

Egan, M., 2011b. Optimisation of Vault Operational Conditions. LLW Repository Ltd Report LLWR/ESC/R(11)10043.Environment Agency, 2005. The Environment Agency’s Assessment of BNFL’s 2002 Environmental Safety Cases for the Low-Level Radioactive Waste Repository at Drigg. Environment Agency Report NWAT/Drigg/05/001, Version 1.0. June 2005.

Environment Agency, 2005. The Environment Agency’s Assessment of BNFL’s 2002 Environmental Safety Cases for the Low-Level Radioactive Waste Repository at Drigg. NWAT/Drigg/05/001, Version: 1.0.

Environment Agency, 2009. Review of LLW Repository Ltd’s 'Requirement 2' submission. Technical Review of Volume 2: Assessment of Options for Reducing Future Impacts from the LLWR. Environment Agency Report NWAT/LLWR/09/002.

Environment Agency, 2010. Guidance on monitoring landfill gas surface emissions, LFTGN07 v2 2010.

Environment Agency, 2015a. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Overview Report.

Environment Agency, 2015b. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Safety Case Management.

Environment Agency, 2015c. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Inventory and Near-field.

Environment Agency, 2015d. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Site Understanding and Evolution.

Environment Agency, 2015e. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Assessment.

Environment Agency, 2015f. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Issues Resolution Forms.

Environment Agency, 2015g. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Forward Issues.

Environment Agency, 2015h. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Issues Assessment Forms.

Environment Agency, 2015i. Review of LLW Repository Ltd's 2011 Environmental Safety Case: Non-technical Summary.

Environment Agency, 2015j. Vault 8 ISO Container Inspection Report.

Environment Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2009. Near-surface Disposal Facilities on Land for Solid Radioactive Waste: Guidance on Requirements for Authorisation.

Fairhurst, A., 2013. Engineering Assessment Framework. Environment Agency Letter 29th July 2013, ref LLWR/13/009/0.

Halcrow, 2010a. Main SMP2 document, Report Prepared for the North West and North Wales Coastal Group as part of the Second Round Shoreline Management Plan for Cell 11.

Halcrow, 2010b. North West & North Wales Coastal Group: North West England and North Wales Shoreline Management Plan SMP2 Main SMP2 Document.

Harper, A. and Dickson, M., 2011. ESC - Trench Remediation Studies - Potential Approaches and Options for Implementation. Serco Report SERCO/TAS/003677/001, February 2011.

Hartley, L., Applegate, D., Couch, M., Jackson, P. and James, M., 2011. Hydrogeological Modelling for the 2011 LLWR ESC. Phase 2. Serco Report No. SERCO/TCS/E003632/005 Issue 5, April 2011.

Henderson, E. and Bechelli, B., 2011. A Water Balance for the Cap over the Trenches. NNL Report (11)11894, December 2011.

Hickford, G. and Smith, V., 2011. RECALL Interviews. Serco Report SERCO/TAS/003756.01/002 Issue 2.

Jackson, C., Couch, M., Yates, H., Smith, V., Kelly, M. and James, M., 2011. Elicitation of Uncertainties for LLWR. Serco Report SERCO/TAS/E003796/010, Issue 2, April 2011.

Jefferies, N., 2011. Trench Cap Cut-off wall Performance Review Incorporating the 2011 Annual Response to Environment Agency Schedule 7 Requirement 7. LLW Repository Ltd Report RP/3409246/PROJ/00220/A, Issue 1, 1 May 2011.

Jefferies, N., 2012. LLWR, Vault 8 Containers Issues Project: Position Paper. LLW Repository Ltd Report RP/LLWRGR/PROJ/00139 ISSUE A, December.

Jefferies, N., 2013a. LLWR Vault 8 Containers Issues Project: Action Plan. LLW Repository Ltd Report RP/LLWRGR/PROJ/00141 ISSUE A, March 2013.

Jefferies, N., 2013b, RFQ 5772, Relating to Non-destructive Testing of HHISO Containers at LLWR. AMEC Report, January 2013.

Lean, C. and Willans, M., 2010. A Features, Events & Processes and Uncertainties Tracking System to Support the 2011 ESC. NNL Report (09)10762.

Lean, C., Wareing, A., Paksy, A. and Small, J., 2011. Consideration of Potential Emplacement Strategies for the LLWR. NNL Report (09)10697, March 2011.

LLW Repository Ltd, 2008. Annual Performance Assessment of the Interim Cap and Cut-off Wall at the LLWR Trenches. LLW Repository Ltd Report RP/103657/4510034188/PROJ/00002/A, April 2008.

LLW Repository Ltd, 2009. Annual Performance Assessment of the Interim Cap and Cut-off Wall at the LLWR Trenches. LLW Repository Ltd Report RP/103657/4510034188/PROJ/000019/A, April 2009.

LLW Repository Ltd, 2010. Annual Performance Assessment of the Interim Cap and Cut Off Wall. LLW Repository Ltd Report Aker 26/4/10, RP/103547/4510034188/PROJ/00038 Rev A1, 2010.

LLW Repository Ltd, 2011a. The 2011 Environmental Safety Case. Optimisation and Development Plan. LLW Repository Ltd Report LLWR/ESC/R(11)10025, May 2011.

LLW Repository Ltd, 2011b. The 2011 Environmental Safety Case. Engineering Design. LLW Repository Ltd Report LLWR/ESC/R(11)10020, May 2011.

LLW Repository Ltd, 2011c. The 2011 Environmental Safety Case. Hydrogeology. LLW Repository Ltd Report LLWR/ESC/R(11)10022,May 2011.

LLW Repository Ltd, 2011d. The 2011 Environmental Safety Case. Site Evolution. LLW Repository Ltd Report LLWR/ESC/R(11)10023 May 2011.

LLW Repository Ltd, 2011e. The 2011 Environmental Safety Case. Assessment of Long-Term Radioactive Impacts. LLWR/ESC/R(11)10028, May 2011.

LLW Repository Ltd, 2011f. The 2011 Environmental Safety Case. Waste Acceptance Criteria. LLW Repository Ltd Report LLWR/ESC/R(11)10026, May 2011.

LLW Repository Ltd, 2011g. The 2011 Environmental Safety Case. Near Field. LLW Repository Ltd Report LLWR/ESC/R(11)10021, May 2011.

LLW Repository Ltd, 2011h. The 2011 Environmental Safety Case. Extended Disposal Area. LLW Repository Ltd Report LLWR/ESC/R(11)10035, May 2011.

LLW Repository Ltd, 2011i. The 2011 Environmental Safety Case - Main Report. LLW Repository Ltd Report LLWR/R(11)10016, May 2011.

LLW Repository Ltd, 2013a, Trench Cap and Cut-off Wall Performance Review Incorporating the 2012 Annual Response to Environment Agency Schedule 9 Requirement 7. LLW Repository Ltd Report RP/LLWRGR/PROJ/00148/A, April 2013.

LLW Repository Ltd, 2013b. Developments Since the 2011 ESC. LLW Repository Ltd Report LLWR/ESC/R(13)10058, Issue 1.

LLW Repository Ltd, 2013c. Development and Application of the LLWR's Environmental Safety Case. Repository Site Procedure RSP 1.25, Issue 1, 09/2013.

LLW Repository Ltd, 2013d. Modification to or Experiment on Existing Plant. Repository Site Procedure RSP 1.27. Issue 6 12/2013.

LLW Repository Ltd, 2013e. 2011 Low Level Waste Repository Environmental Safety Case: Features, Events and Processes and Uncertainty Tracking System. LLW Repository Ltd Spreadsheet MASTER 2011 FEP List_LLWR04127061103_0_2 - ajb7 macro Jan 2013.

LLW Repository Ltd, 2013f. Repository Site Procedure 2.25. Development and Application of LLWR's Environmental Safety Case. Issue 1, September 2013.

LLW Repository Ltd, 2013g. The LLWR Environmental Safety Case. Application to Vary LLWR's Permit. LLW Repository Ltd Report LLWR/ESC/R(13)10057, Issue 1.

LLW Repository Ltd., 2014. Waste Services Contract. Waste Acceptance Criteria - Low Level Waste Disposal. LLW Repository Ltd Report WSC-WAC-LOW - Version 4.0 - March 2014.

Nuclear Decommissioning Authority, 2011. UK Radioactive Waste Inventory. Main Report, NDA/ST/STY(11)0004, February 2011.

Nuclear Decommissioning Authority, 2012. Geological Disposal: Review of Baseline Assumptions Regarding Disposal of Core Graphite in a Geological Disposal Facility. NDA Technical Note 16495644, May 2012.

Paulley, A., 2011. Optimisation of Vault Sequencing. LLW Repository Ltd Report LLWR/ESC/R(11)10042.

Paulley, A. and Egan, M., 2011. LLWR Pre- and Post-closure Engineering Optimisation for the LLWR 2011 ESC. Quintessa Report QRS-14430-1 Version 2.

Paulley, A., Garrard, M. and Nutting, M., 2012. LLWR Trench Hydrological Management BAT: Final Report. Quintessa Report QRS-1443ZN-R3.

Penfold, J., Pearce, S., Batandjieva, B. and Sinclair, P., 2010. Development of Strategies for the Institutional Control Period, QRS 1443T-1, June 2010.

Penfold, J., Burrow, J. and Robinson, P., 2013. LLWR Waste Emplacement Strategy: Assessment of the Implications of Voidage in Vault 8. Quintessa Report QRS-1443ZP-1, Version 2.1.

Serco, 2011. Trench Cap and Cut-off Wall Performance Review Incorporating the 2011 Annual Response to Environment Agency Schedule 9 Requirement 7. LLW Repository Ltd Report RP/3409246/PROJ/00220/A, May 2011.

Shaw, N., 2013. Engineering Forward Plan to Support the Environmental Safety Case. LLW Repository Ltd Report RP/LLWRGR/PROJ/00142 Issue A, April 2013.

Shevelan, J., 2012a. ESC Technical Memo: Response to Environment Agency Query about Vault 8 Flow Paths, LLWR/ESC/Mem(12)183a, December 2012.

Shevelan, J., 2012. Response to IRF ESC-TQ-SUE-024: Concrete Slab Performance. LLW Repository Ltd Technical Memo LLWR/ESC/Mem(12)154.

Small, J., Randall, M. and Lennon, C., 2011. Physical and Chemical Heterogeneity on a container scale. NNL Report (09)10694, March 2011.

Smith, R., 2014. Advice to Environment Agency Assessors on the Disposal of Discrete Items, Specific to the Low Level Waste Repository, Near Drigg, Cumbria.

Thorne, M., 2008. Estimates of Cap Infiltration and Erosion. Nexia Solutions Report (08) 9274.

Tonks, D., 2011. Cap Settlement. LLW Repository Ltd Report LLWR/ESC/R(10)10036, April 2011.

Williams, L. and Proctor, A., 2007. Low Level Waste Repository (LLWR) Modular Vaults Project: Single Option Selection Process. British Nuclear Group Project Services Report BNGPS/LLWR/MV/1/003/1, May 2007.

Wood, A., 2000. Drigg Grouting Demonstration Project. BNFL Project Document.

Westlakes Engineering, 2012a. Identification of Potential Grout Degradation and Shrinkage Mechanisms. Westlakes Engineering Report RP/533/01 Issue 1, September 2012.

Westlakes Engineering, 2012b. Review of Grouting Procedures, Westlakes Engineering Report, RP/533/02, September 2012.

URS, 2012. LLWR: Site Optimisation and Closure Works: Regulation 22 Response: Engineering Design. March 2012.

URS, 2013. LLWR: Site Optimisation and Closure Works. Regulation 19 Response – Engineering. October 2013.

6. Appendix 1 - Issue Resolution Forms

6.1. Introduction

As outlined in Section 1.3, Issue Resolution Forms (IRFs) are detailed records of concerns and queries raised as part of our review of the ESC. Each IRF includes one or more actions. LLW Repository Ltd was required to provide a substantive response to the action(s) specified on the IRF by the specified date(s). Issues were closed out only when we had determined that the LLW Repository Ltd response adequately addresses the issue.

6.2. Issue Resolution Forms

Summaries of Regulatory Issues (RIs), Regulatory Observations (ROs) and Technical Queries (TQs) raised during our review of the 2011 optimisation and engineering work are provided in Table 2, Table 3 and Table 4 respectively. These IRFs are reproduced in full in Environment Agency (2015f). Optimisation IRFs were raised under the Assessments and Optimisation area (ASO), whilst engineering IRFs were either raised under Inventory and Near Field (INF) or Site Understanding (SUE). The IRFs are not sequentially numbered. This is because some IRFs were identified as possible queries but not issued, for example, following further detailed review of information provided in support of the 2011 ESC, or following on from clarifications provided by LLW Repository Ltd. All IRFs have now been closed.

Table 1: Regulatory Issues

Regulatory Issue number	Title	Summary
ESC-RI-ASO-001	Optimisation of vault sequencing	We asked LLW Repository Ltd to provide an explicit optimisation case for the proposed sequencing of vaults, taking account of the current understanding of the disposal system and of the site and its evolution.
ESC-RI-ASO-002	Optimisation of vault operational conditions	We asked LLW Repository Ltd to provide an explicit optimisation case for the proposed operational configuration of vaults, specifically the absence of measures to minimise contact between incoming water and the waste during vault operation.
ESC-RI-ASO-003	Optimisation of disposal system in relation to possible future waste retrieval or facility protection	We asked LLW Repository Ltd to provide an explicit optimisation case that possible future actions to retrieve waste from the vaults or protect the LLWR against coastal erosion have not been unreasonably hindered or precluded.
ESC-RI-INF-005	Container condition monitoring and sampling programme	We requested further information on the condition of the ISO freight containers in Vault 8 and confirmation that the grouted container performance assumptions used in the 2011 ESC can be achieved over the whole operational life of the site. We also requested an appropriate programme of inspection, monitoring and sampling of the

Regulatory Issue number	Title	Summary
		containers.

Table 2: Regulatory Observations

Regulatory Observation number	Title	Summary
ESC-RO-SCM-001	Change control for the ESC	We requested that LLW Repository Ltd provide a programme detailing how it will develop and achieve a robust change control process for the ongoing management of the ESC and its relationship to site operations. Then to demonstrate delivery of a robust change control process, captured within written management arrangements, for the ongoing management of the ESC and its relationship to site operations.
ESC-RO-ASO-005	Safety functions	We asked LLW Repository Ltd to explain why a safety function approach was not utilised. The IRF also asked for improvements in the presentation of safety functions in the Level 1 report and to submit a final version of the FEP and uncertainty tracking system.
ESC-RO-INF-003	Non-standard disposals to Vault 8	We requested information on the procedures in place for dealing with non-standard disposals to the LLWR. This IRF also requested a list of all non-standard disposals that had been consigned to Vault 8.
ESC-RO-INF-003b	Non-standard disposals to Vault 8	We asked LLW Repository Ltd to provide further detail on their procedures in place pre-2002 and between 2002-2011 for accepting non-standard disposals, and how these were controlled and assessed.
ESC-RO-SUE-001	Final capping of the trenches	We asked LLW Repository Ltd to demonstrate that the interim trench cap can reasonably be made to perform, with a high degree of confidence, sufficiently well to ensure consistency with the assumptions in the ESC until completion of the last stage of the final capping.
ESC-RO-SUE-009	Consolidation and resolution of engineering uncertainty	We asked LLW Repository for a strategic level engineering improvement plan designed to provide engineering designs for a number of engineering design elements including the capping system and the leachate collection system.

Table 3: Technical Queries

Technical Query number	Title	Summary
ESC-TQ-ASO-001	Implementation of emplacement strategies in Vault 8	We asked LLW Repository Limited to provide a clear statement of its plans in relation to implementation of emplacement strategies within Vault 8 and of waste already within Vault 8.
ESC-TQ-ASO-007	Selective retrievals study: GDF disposal costs	We sought clarification of a number of discrepancies relating to retrieval costs. We also asked LLW Repository Ltd to take account of income derived from the increases in the available disposal void.
ESC-TQ-INF-006	Ratio of Waste to Grout Infill	We requested further information on the impact of waste packages in which the ratio of waste to grout is less than the average stated in the 2011 ESC of 60:40. We sought evidence that these waste packages would not impact on the near field engineering and the chemical evolution of the near field.
ESC-TQ-INF-007	Understanding and optimisation of surcharge requirements and final cap placement timing	We sought clarification of the design and monitoring of surcharging material placed over the trench waste before the placement of the final capping system.
ESC-TQ-INF-018	Trench cap leakage	We asked LLW Repository Ltd to amend the trench cap infiltration values used in the 2011 ESC to represent the latest available data and so as to reflect the best available measured leakage rate.
ESC-TQ-SUE-023	Cap slope stability assessment request	We asked LLW Repository Ltd to produce a slope stability assessment for the steepest part of the single dome restoration design.
ESC-TQ-SUE-024	Assumed concrete slab performance	We asked LLW Repository Ltd to clarify the performance and role of the concrete slab joints in the 2011 ESC.
ESC-TQ-SUE-026	Seismic assessment of cap stability	We asked LLW Repository Ltd to present evidence that the 2002 PCSC seismic assessment remains relevant to the 2011 ESC reference design and continues to represent best practice.

7. Appendix 2 - Recommendations

7.1. Introduction

Recommendations raised as a result of our review of the 2011 ESC represent areas where we see scope for possible improvement or development, but which are relatively minor in nature relative to FIs. As a matter of good practice we expect LLW Repository Ltd to address these recommendations and will expect a mechanism to be put in place to track them.

7.2. Recommendations

Table 4 summarises the recommendations made in this report. Further details are provided in Section 2 and 3.

Table 4: Optimisation and engineering recommendations

Recommendation number	Summary of recommendation
O&E1	Links between the developing engineering design and the ESC should be clearly documented in formal procedures.
O&E2	At future opportunities (for example periodic reviews of the ESC) LLW Repository Ltd should revisit the optimisation decisions presented in the 2011 ESC to make sure they remain valid.
O&E3	Future updates of the ESC should provide greater clarity on how operational safety issues and decisions are factored in to the optimised design.
O&E4	Future iterations of the ESC might benefit from a narrative describing past optimisation decisions, including those that took place between the 2002 ESCs and the 2011 ESC.
O&E5	LLW Repository Ltd should make the weight attributed to all factors considered in future optimisation studies more explicit (whether qualitatively or quantitatively), allowing greater clarity on how decisions about option choices have been reached.
O&E6	LLW Repository Ltd should reassess the cost model for retrieval and re-disposal of certain trench waste if the English policy for disposal of higher activity waste changes.
O&E7	Because of the predicted likelihood of coastal erosion of the site, LLW Repository Ltd should make sure that future operational and design decisions do not unnecessarily foreclose options for the retrieval of waste in existing and future vaults.
O&E8	We recommend that the company reviews the viability of selective retrievals and the associated environmental safety arguments in future updates of the ESC.
O&E9	Future updates of the ESC and SDP should consider how the design accommodates (or does not foreclose) understanding around future likely uses of the site and builds in sufficient flexibility to address uncertainties around this.
O&E10	The company should continue to develop strategies for the

Recommendation number	Summary of recommendation
	period of institutional control and to incorporate them into future updates of the ESC.
O&E11	LLW Repository should consider the potential for the provision of passive engineered features to mitigate and slow disruptive processes, thus also serving to reduce individual annual risks.
O&E12	LLW Repository Ltd should investigate the implications of diffusive flow through the engineered barriers, or substantiate why these flows are insignificant compared with advective fluxes.
O&E13	In future optimisation decision making, we expect to see a more effective linkage between hydraulic performance and design objectives.
O&E14	Future updates of the ESC would benefit from clear documentation of the process LLW Repository Ltd has used to determine the engineering design, which provide details of baseline assumptions, inputs to the decision making process and substantiation of chosen components.
O&E15	LLW Repository Ltd should investigate the feasibility of reducing the angle of the steepest cap slopes or consider measures to mitigate long-term erosion.
O&E16	To optimise the basal drainage system for each vault, we recommend that the functional requirements of this system (drainage capacity) are defined on a vault by vault basis.
O&E17	We recommend that future updates of the ESC provide an effective linkage between the environmental safety objectives and the detailed engineering performance specifications.
O&E18	Where engineering systems or barriers provide multiple safety functions we recommend that LLW Repository Ltd differentiates between the primary environmental safety functions and the secondary environmental safety functions.
O&E19	LLW Repository Ltd should consider carrying out destructive container investigations similar to those carried out by Wood (2002).
O&E20	We consider it important that LLW Repository Ltd continues to review the use of non-destructive container inspection methods to meet its operational waste packaging information needs.
O&E21	LLW Repository Ltd should make sure that elicited data are consistent with and where possible use outputs from future engineering performance assessments.
O&E22	LLW Repository Ltd should undertake further investigations into the timing, mechanisms and uncertainty associated with the failure and degradation of performance of the engineered systems during and after the period of authorisation.
O&E23	LLW Repository Ltd should bring the engineering performance FEPs identified in Table A1.4 of Lean and Willans (2010) into the FEP and uncertainty tracking system,

Recommendation number	Summary of recommendation
	or suitable future alternative systems.
O&E24	We recommend that the uncertainty associated with the performance of the leachate management system and basal drainage system is better reflected in any future FEP and uncertainty tracking system.
O&E25	LLW Repository Ltd should develop a specific FEP for the uncertainty associated with the magnitude and timing of past and future container settlement.
O&E26	In future updates of the FEP and uncertainty tracking system (or future alternative systems) we recommend an increased level of detail in FEPs covering the engineered system and its performance, and the associated uncertainties. These FEPs should be effectively linked to the developing design and uncertainties associated with it.
O&E27	We recommend that prior to construction of the final engineered cap, LLW Repository Ltd ensures, through monitoring, that waste settlement achieved through the application of surcharging provides evidence that any remaining potential for waste settlement is consistent with assumptions made within the 2011 ESC.
O&E28	LLW Repository Ltd should give careful consideration to the performance benefits from the profiling materials, including how the profiling material will affect leakage through the cap.
O&E29	LLW Repository Ltd should consider engineering profiling and fill materials as part of the engineered safety systems.
O&E30	LLW Repository Ltd should consider further optimisation of the final design of the cap surface, including cover system and vegetation.
O&E31	We recommend that future updates of the ESC more clearly describe the role of the cut-off wall, in conjunction with the basal drainage layer and in-situ granular material in reducing the extent and mitigating the consequences of overtopping.
O&E32	To validate the ongoing performance of the cut-off wall in limiting groundwater ingress into the vaults, LLW Repository Ltd should consider incorporation of monitoring infrastructure between the cut-off wall and the vaults.
O&E33	The design should, as far as possible, ensure that no actions are taken that will preclude long-term maintenance or replacement of infrastructure required throughout the period of institutional control.

8. Appendix 3 - Forward Issues

8.1. Introduction

Forward Issues (FIs) raised as a result of our review of the 2011 ESC represent areas that we believe require, or could benefit from, further work or clarification in the future.

FIs are categorised in terms of the importance of the issue (for example the scope for improvement of the ESC against the GRA) and likely effort required to address the issue (Table 5).

Table 5: FI categories

Category	Summary	Explanation
A1	More important, shorter term	An issue that is expected to be important in supporting the delivery of an acceptable update of the ESC in the future and where we believe there is a need to address the issue well in advance of the next major ESC update. LLW Repository Ltd is likely to need to provide substantial additional information, or to significantly change approach. We expect plans to be put in place to address these issues and ongoing reports on progress. Such reporting might, for example, include detailed plans of action, descriptions of proposed approaches, models or data, or results from interim or provisional analyses.
A2	More important, long-term	An issue that is expected to be important in supporting the delivery of an acceptable update of the ESC in the future, but where this improvement can be delivered over relatively long timescales. LLW Repository Ltd is likely to need to provide substantial additional information, or to significantly change approach. We expect ongoing but infrequent reports on progress with these issues. Such reporting might, for example, include detailed plans of action, descriptions of proposed approaches, models or data, or results from interim or provisional analyses.
B1	Important, shorter term	Issues of less importance than category ‘A’. LLW Repository Ltd will need to provide some additional information, evidence or analysis well in advance of the next major ESC update. Plans should be put in place to deliver this information. Generally we estimate the level of effort needed to address this category of issue will be substantially less than for category A. We expect reports on progress with these issues, but with less emphasis than for Category A.
B2	Important, long-term	Issues of less importance than category ‘A’. LLW Repository Ltd will need to provide some further information, evidence or analysis, but over relatively long timescales or as part of the next ESC update. Generally we estimate the level of effort needed to address this category of issue will be substantially less than for category A. We expect only infrequent reports on progress with these issues and with less emphasis than for

Category	Summary	Explanation
		Category A.
C	Additional evidence / improvements in approach	Of lesser importance but of value in improving the ESC. Issues where we require limited reporting or information in advance of any updated ESC.

We will agree with LLW Repository Ltd when and how it intends to address these issues, and will formally track progress made to resolve them.

8.2. Engineering and Optimisation Forward Issues

A summary of FIs raised during our review of the 2011 ESC optimisation and engineering work is provided in Table 6 6. FIs are reproduced in full in Environment Agency (2015g).

Table 6: Engineering and optimisation Forward Issues

Forward Issue number	Title	Categorisation	Summary of issue
ESC-FI-001	Cap settlement issues	A1	LLW Repository Ltd should develop and implement a work programme to identify an optimised cap design and container stack heights.
ESC-FI-007	Inaccessible voidage minimisation procedures and emplacement strategies	B1	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.
ESC-FI-023	Leachate management strategy	A1	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.
ESC-FI-024	Gas management strategy	A2	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 period of authorisation.
ESC-FI-025	Protection of waste prior to final capping	A1	LLW Repository Ltd should develop and implement a programme of work to develop an optimised container design and

Forward Issue number	Title	Categorisation	Summary of issue
			restoration sequence that provides adequate protection to waste containers and minimises discharges to the environment.
ESC-FI-026	Engineering delivery	A1	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.
ESC-FI-027	Cap performance assessment	A1	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.
ESC-FI-029	Management of elicited data	C	LLW Repository Ltd should develop documented procedures for the future management of elicited data.

List of abbreviations

AD	Anno Domini
ALARA	As low as reasonably achievable
AP	After present
BAT	Best available techniques
BES	Bentonite enhanced soil
BNFL	British Nuclear Fuels Limited
CQA	Construction quality assurance
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EDA	Extended disposal area
EPA	Engineering performance assessment
EPR10	Environmental Permitting (England and Wales) Regulations 2010, as amended
EQS	Environmental quality standard
ESC	Environmental safety case
FEP	Features, events and processes
FI	Forward issue
GRA	Guidance on requirements for authorisation (of near-surface disposal facilities on land for solid radioactive wastes)
GRM	Generalised Repository Model
HER	Hydrologically effective rainfall
HRA	Hydrogeological risk assessment
IAF	Issue assessment form
ICE	Institute of Civil Engineers
ILW	Intermediate level waste
INF	Inventory and near field
IRF	Issue resolution form
ISO	International Standards Organization
LLW	Low level waste
LLWR	Low Level Waste Repository near Drigg, Cumbria
mAOD	Metres above ordnance datum
mSv	Millisievert
NDA	Nuclear Decommissioning Authority
NNL	National Nuclear Laboratory

NRG	Nuclear Regulation Group (of the Environment Agency)
NWAT	Nuclear Waste Assessment Team
O&E	Optimisation and engineering
ONR	Office for Nuclear Regulation
PCSC	Post-closure safety case
PoA	Period of authorisation
R&D	Research and development
RDA	Reference disposal area
RECALL	A programme used to elicit information on disposal practices at the LLWR from individuals with experience in the area
RI	Regulatory issue
RO	Regulatory observation
RSP	Repository site procedure
RWM	Radioactive Waste Management Limited.
RWMD	Radioactive Waste Management Directorate
SDE	Site development and engineering
SDP	Site development plan
SI	International system of units
SLC	Site licence company
SUE	Site understanding and evolution
Sv	Sievert
TBq	Terabequerel
TQ	Technical query
UKRWI	United Kingdom radioactive waste and materials inventory
WAC	Waste acceptance criteria

Glossary

Term	Definition
Active institutional control	Control of a disposal site for solid radioactive waste by an authority or institution authorised under EPR10, involving monitoring, surveillance and remedial work as necessary, as well as control of land use.
Activity	In nuclear sciences and technologies, 'activity' is the International System of Units (SI) quantity related to the phenomenon of natural and artificial radioactivity.
Aerobic	An environment or condition where oxygen is present.
Anaerobic	An environment or condition where oxygen is absent.
Basal drainage layer	A granular drainage layer located below the base of the vault.
Bath tubbing (over-topping)	The phenomenon whereby leachate collects within a disposal facility (e.g. the vaults or trenches) and builds up to such a level that it overflows.
Becquerel (Bq)	Becquerel is the derived SI unit of radioactivity equal to one disintegration per second. Activities are commonly documented in terms of megabecquerels (MBq or 10^6 Bq), gigabecquerels (GBq or 10^9 Bq) and terabecquerels (TBq or 10^{12} Bq).
Best available techniques (BAT)	The latest stage of development (state of art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste.
Cap	Engineered layer covering waste in the trenches and vaults to limit the amount of water entering the disposed waste and minimise the risk of intrusion from human and animal activities.
Complexant	'Complexing agents' are chemicals that can bind strongly to metal ions and significantly increase their solubility or decrease their ability to sorb onto solids. They may be an individual atom, molecule or functional group that binds to metal with one or more bonds. The bonding may be ionic or coordinate bonds.
Conservative (of assumptions and data)	Cautious in the sense that impacts would be overestimated.
Consignor (of waste)	An organisation or person that sends waste to the repository.
Cut-off wall	A generic term for a low hydraulic conductivity wall constructed below ground level that is intended to reduce (cut-off) lateral water seepage into or out of part of a site.

Differential settlement	Different settlement between two adjacent stacks in the vaults or between adjacent locations of waste in the trenches.
Diffusion	Transport of chemical species along a concentration gradient, within a solid, liquid or gaseous phase.
Discrete items	Discrete items are distinct items of waste that may in future be recognisable as unusual or not of natural origin and so could be a focus of curiosity or interest and potentially recovered, recycled or re-used by persons.
Disposal	Disposal is the emplacement of waste in a specialised land disposal facility without intent to retrieve it at a later time; retrieval may be possible but, if intended, the appropriate term is storage.
Dose constraint	A restriction on annual dose to an individual, which may either relate to a single source or to a complete site, in order to ensure that when aggregated with doses from all sources, excluding natural background and medical procedures, the dose limit is not exceeded. The dose constraint places an upper bound on the outcome of any optimisation study and, therefore, limits any inequity that which might otherwise result from the economic and social judgements inherent in the optimisation process. The Government has set a maximum dose constraint value of 0.3 mSv y^{-1} when determining applications for discharge authorisations from a single new source, and a dose constraint value of 0.5 mSv y^{-1} for a complete site (which may include several sources with more than one operator).
Elicitation	A structured process in which a group of experts are brought together to derive logical theoretical outcomes or to solve problems.
Emplacement	The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.
Emplacement strategy	A strategy to control the locations in which certain waste streams and waste consignments are emplaced in the vaults, for example, not placing certain waste in the upper levels of stacks in the vaults. This would have the effect of reducing the probability of inadvertent human intrusion into such waste. An emplacement strategy may be necessary to meet dose constraints and dose guidance levels, or it might be an optimisation measure to minimise the environmental impact of disposals to the LLWR.
Engineered barrier	A barrier that is designed to protect from human intrusion into disposed waste and minimise the release of contaminants, both radiological and non-radiological, from the disposal facility, consequently minimising the dose to humans and non-human biota.
Engineering performance assessment (EPA)	An evaluation of engineered system degradation and associated failure mechanisms.
Environmental permit	A permit issued under the Environmental Permitting (England and Wales) Regulations 2010.

Environmental safety	The safety of people and the environment both at the time of disposal and in the future.
Environmental safety case (ESC)	The collection of arguments, provided by the developer or operator of a disposal facility, that seeks to demonstrate that the required standard of safety for people and the environment, both at the time of disposal and in the future, will be achieved.
Environmental safety functions	The various ways in which the components of the disposal system may contribute towards environmental safety.
Environmental safety strategy	An approach or course of action designed to achieve and demonstrate environmental safety.
Exposed group	For a given source, any group of people within which the exposure to radiation is reasonably homogeneous; where the exposure is not certain to occur, the term 'potentially exposed group' is used.
Extended disposal area (EDA)	An extended area of the repository, beyond but including the Reference Disposal Area, which is considered in the 2011 ESC to be sufficient to dispose of all waste requiring vault disposal in the United Kingdom Radioactive Waste Inventory.
Features, events and processes (FEPs)	Any factors that may influence the disposal system.
Forward issue (FI)	Areas of work that we believe it is important for LLW Repository Ltd to progress as part of its forward improvement plan. Areas where we see scope for continued improvement in the ESC and its implementation.
Groundwater	All water which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil.
Grout port hole	This is the hole located on the lid of the ISO freight containers, where the grout is pumped into the container to encapsulate the waste.
Gull wing design	A previous repository restoration design incorporating two discrete landforms for the vaults and trenches respectively.
Human intrusion	Any human action that accesses the waste or that damages a barrier providing an environmental safety function after the period of authorisation.
Hydraulic conductivity	A property of soil or rock, that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid.
Infiltration	The process in which a fluid passes into the pores of a solid.
Intermediate level waste (ILW)	Radioactive waste exceeding the upper activity boundaries for low level waste but which does not need heat to be taken into account in the design of disposal facilities.
ISO freight container	A steel container built to standard dimensions defined by the International Standards Organization (ISO), which can

	be loaded and unloaded, stacked and transported efficiently over long distances without being opened. Currently, most wastes intended for disposal in the vaults at LLWR are placed in half-height ISO containers licensed for LLW transport. The 2011 ESC assumes that this will continue to be the case.
Issue assessment form (IAF)	Issues raised during our review of the 2002 ESCs, which the operators of the LLWR were required to address as part of the development of the 2011 ESC, were detailed within IAFs.
Issue resolution form (IRF)	A template form used to record and track issues raised as part of the 2011 ESC review, along with their resolution. Each form provides a record of concerns or questions along with one or more actions for LLW Repository Ltd. LLW Repository Ltd recorded or summarised its response on the form, which was then reviewed by the Environment Agency and closed when a satisfactory response was received.
Leachate	Any liquid which has been in contact with wastes. Leachate is collected in the base of vaults and trenches and arises as a result of the infiltration of rainwater or groundwater.
Low level waste (LLW)	In government policy, low level waste is defined as 'radioactive waste having a radioactive content not exceeding four gigabecquerels per tonne (GBq te^{-1}) of alpha or 12 GBq te^{-1} of beta/gamma activity'. It consists largely of paper, plastics and scrap metal items that have been used in the nuclear industry, hospitals and research establishments. In future, there will also be large volumes of LLW in the form of soil, concrete and steel, as existing nuclear facilities are decommissioned.
Monitoring	Taking measurements so as to be aware of the state of the disposal system and any changes to that state. This may include measuring levels of radioactivity in samples taken from the environment, and also measuring geological, physical and chemical parameters that are relevant to environmental safety and which might change as a result of construction of the disposal facility, waste emplacement or closure.
Near field	In the context of the assessments in support of the LLWR ESC, the near field consists of the waste and engineered barriers.
Non-standard disposals	Disposals to the LLWR vaults not made within the commonly used ISO freight containers. Examples have included the direct disposal of cylinders, flasks, ingots or alternative waste containers.
Optimisation	Optimisation is the principle of ensuring that radiation exposures are as low as reasonably achievable (ALARA) in the given circumstances. It is a key principle of radiation protection recommended by the International Commission on Radiological Protection (ICRP) and incorporated into UK legislation.
Organic	A class of chemical compounds that include carbon within their structure.

Overtopping (bath-tubbing) — The phenomenon whereby leachate collects within a disposal facility (e.g. the vaults or trenches) and builds up to such a level that it overflows LLW Repository Ltd also uses the term 'bath-tubbing' when referring to this phenomenon.

Pathway — A route or means by which a receptor could be, or is exposed to, or affected by a contaminant. Four pathways are considered in the 2011 LLWR ESC: groundwater, gas, natural disruption (coastal erosion) and human intrusion.

Period of authorisation — The period of time during which disposals are taking place and any period afterwards while the site is under active institutional control.

Permeability — A measure of the capability of a porous rock or sediment to permit the flow of fluids through its pore spaces.

Post-closure safety case — The safety case presented as part of the ESC that covers the time after the end of the period of authorisation.

Potentially exposed groups (PEGs) — For a given source, such as a near-surface disposal facility, an exposed group is any group of people within which the exposure to radiation is reasonably homogeneous. Where the exposure is not certain to occur, the term ‘potentially exposed group’ is used.

Profiling material — The material put in place over the disposed waste prior to placement of the engineered cap to induce settlement and compaction of the waste (surcharging), ensure that any further settlement or compaction will not affect the functionality of the cap and create the final profile of the cap.

Radioactive decay — Spontaneous disintegration of a radionuclide accompanied by the emission of ionising radiation in the form of alpha or beta particles or gamma rays.

Radioactivity — The emission of alpha particles, beta particles, neutrons and gamma or x-radiation from the transformation of an atomic nucleus.

Radiological capacity — An inventory of radioactive material that the facility is capable of accepting based on the ESC.

Radionuclide — An unstable form of an element that undergoes radioactive decay.

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RECALL interviews — A systematic and recorded interview technique carried out by a third party using standard questions. The objective of the RECALL interview is to elicit and record information from the interviewee based on their experiences and knowledge. RECALL was used by LLW Repository Ltd to elicit information on past disposals to the LLWR.

Receptors — Something that could be adversely affected by a contaminant, such as people, an ecological system, property or water body.

Reference disposal area (RDA) — The disposal area including the trenches and Vaults 8 to 14.

Regulatory issue (RI) — An issue raised in an issue resolution form during our review of the 2011 ESC where deficiencies in the case

	were identified. An RI is a deficiency sufficiently serious that, unless or until it is resolved, we will either: (a) not grant a permit; or (b) grant a permit constrained by major limiting conditions (as distinct from information or improvement conditions) defined by us to mitigate the consequences of the RI.
Regulatory observation (RO)	An issue raised in an issue resolution form during our review of the 2011 ESC where deficiencies in the case were identified. An RO is a deficiency not sufficiently serious to prevent us issuing a permit but sufficiently serious that, unless or until it is resolved, we will include an improvement or information condition in the permit requiring defined actions on defined timescales to resolve it (or to demonstrate suitable and sufficient progress towards resolving it).
Retrievability	A characteristic of the design of the waste package and/or the disposal facility that facilitates recovery of waste after emplacement.
Risk guidance level	A level of radiological risk from a disposal facility that provides a numerical standard for assessing the environmental safety of the facility after the period of authorisation.
Scenario	One of several possible descriptions of the evolution of the disposal facility and its surroundings from the time of site closure as a result of natural, human-induced, waste-related and engineering-related events and processes.
Seismic	Of or having to do with earthquakes.
Shielding	The placement of material between a radiation source and a human or non-human that results in a significant reduction in the radiation energy reaching the human or non-human. For example, placing lead sheets between a radioactive source and a person will reduce the radiation exposure to that person.
Site development plan (SDP)	Sets out proposals and assumptions on operations, remedial activities, vault design, capacity and future waste disposal practice, closure design and management up to the end of the period of authorisation. Forms the basis of assessment of repository performance.
Specific activity	Radioactivity per unit mass of a waste.
Surcharge	The material added to the top of the waste prior to the engineered cap being placed over the trenches, to induce settlement in the waste materials and thus limit the extent of settlement that the engineered cap will be initially subjected to.
Technical query (TQ)	An issue raised in an issue resolution form during our review of the 2011 ESC where deficiencies in the case were identified. TQs are the least significant of the issues raised and represent a deficiency not sufficiently serious for us to require defined action by LLW Repository Ltd but sufficiently significant that we would request action.
Trench	A trench is an excavation in the ground into which loose waste is tipped.

UK Radioactive Waste Inventory (UKRWI)	The UKRWI is provided by the Department of Energy and Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA). The inventory provides comprehensive and up-to-date information on radioactive waste in the United Kingdom. It provides a consistent reference source of information for government, its agencies, NDA, and others with a role or interest in the management of radioactive waste. The inventory is routinely updated and published in the public domain, currently on a 3 yearly cycle.
Ullage	The unfilled space at the top of a grouted ISO freight container, immediately below the lid.
Uncertainty	Lack of certainty. A state of limited knowledge that precludes an exact or complete description of past, present or future.
Unsaturated	A volume of material is unsaturated when some or all of the pore space is filled with air.
Vault	A space constructed of reinforced concrete base slabs and walls where wastes are emplaced.
Waste acceptance criteria (WAC)	Quantitative and qualitative criteria, specified by the operator of a disposal facility, for solid radioactive waste to be accepted for disposal. WAC form part of the set of waste acceptance arrangements that ensure the safety of waste disposal at the site.
Waste form	The actual physical state of the waste and its immediate packaging (for example grout and container) that is disposed of at the LLWR.
Waste stream	Waste streams are designated in the UKRWI to summarise waste or a collection of waste items at a particular site, usually in a particular facility or form particular processes or operations. A waste stream is often distinguishable by its radioactive content and, in many cases, also by its physical and chemical characteristics.

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