Review of LLW Repository Ltd's 2011 environmental safety case: Overview report

Issue 1, 15 May 2015

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Executive summary

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

We carried out a comprehensive technical review of the 2011 ESC to determine its adequacy as a submission against our permit requirements. In our review, we considered whether it met the principles and requirements set out in our guidance on requirements for authorisation of near-surface disposal facilities for solid radioactive waste (GRA). This guidance sets out what we expect to see in an ESC. We considered the ESC as submitted in 2011 as well as other technical work carried out up to and including LLW Repository Ltd's permit variation application that we received on 28 October 2013. The findings of this review form a major input to our regulatory decision on permitting the LLWR to dispose of radioactive waste in the future.

This overview report summarises our review of the 2011 ESC. This report is supported by 5 technical review reports. These give more detailed conclusions on the technical adequacy of the 2011 ESC as a basis for permitting future disposals. These reports cover: Safety case management; Inventory and near field; Site understanding; Optimisation and engineering; and Assessment.

Overall, we consider that the 2011 ESC submission is of good quality, generally clear and concise and has addressed the requirements of the GRA. The level of detail in the ESC is proportionate to the hazard associated with the repository. However, during our review we had to ask for information not included in the original submission as well as clarifications and extra technical work to support our review. With this additional information, the 2011 ESC was sufficient and comprehensive enough for us to complete our review.

In the 2011 ESC, LLW Repository Ltd has demonstrated a greater understanding of both disposed waste and likely disposals in the future (in terms of radioactivity, waste form and composition), as well as the environmental context of the site and how it is likely to change over time. LLW Repository Ltd has concluded that the repository is almost certain to be eroded by the sea. The coast currently lies approximately 400 metres from the nearest part of the site boundary. The company projects that erosion of the repository is likely to start within a period of a few hundred to a few thousand years from now. The 2011 ESC has taken this into account. The ESC has shown that, irrespective of any future work to prevent coastal erosion, radiological doses and risks remain below regulatory and internationally accepted criteria for the protection of people and the environment.

The 2011 ESC and supporting work have also addressed a number of other topics that we have considered important in making the case for continuing to dispose of waste at the LLWR. In particular, our review has looked at:

- an assessment of the impact of the poor condition of some containers in Vault 8 on the final cap design and its potential for settlement
- an assessment of the impact of waste heterogeneity following coastal erosion of the facility or human intrusion into it
- an assessment of non-radiological impacts (for example toxicity)
- engineering design and optimisation to demonstrate that impacts are as low as reasonably achievable (ALARA)

In each case, we are confident that LLW Repository Ltd has provided enough evidence to prove that it has met the requirements of the GRA.

For the period of authorisation, which comprises the period of disposal operations and the period of management following completion of disposals until the end of management and regulatory control of the LLWR, we consider that LLW Repository Ltd has demonstrated that impacts will remain at acceptably low levels. After the period of authorisation, LLW Repository Ltd has

projected that doses and risks will remain below our regulatory criteria using a reasonable range of cautious assumptions about future scenarios and behaviour of humans and biota. Impacts associated with the non-radioactive component of disposals, though subject to uncertainty, are also not projected to cause harm to humans or the environment. Consequently, we consider that the 2011 ESC has demonstrated that disposing of radioactive waste at the LLWR now and in the future will not cause harm to people or the environment. We also consider that LLW Repository Ltd has the right resources and management systems in place to carry on operating the site in line with our requirements.

We expect the ESC to continue to develop as a live case with ongoing annual, periodic and major reviews. We also expect a forward programme of work to be developed and maintained. We will work with LLW Repository Ltd to ensure that this forward programme of work meets our regulatory expectations with the aim of ensuring continued improvement to the ESC and continued compliance with the requirements of the GRA. In support of this, we have raised a number of forward issues on important areas where we see scope for continued improvement in the ESC and its implementation. We will monitor progress against these forward issues and will require further improvements to be made so that the ESC continues to meet our expectations. We have also made recommendations on areas where we see scope for possible improvement or development. These forward issues and recommendations should only be one input into the forward programme of work, which should be informed by LLW Repository Ltd's wider understanding of the site, the ESC and monitoring data, amongst other inputs.

Overall, we consider that LLW Repository Ltd has met the requirements of the GRA and its current environmental permit through the 2011 ESC and supporting documents. The evidence is of a suitable standard and quality to support an environmental permit decision on future disposals at the site. We are satisfied that the 2011 ESC and supporting documents demonstrate that further disposal of radioactive waste at the facility will be safe for people and the environment both now and in the long-term. Based on this evidence, we will give our proposed decision on permitting further radioactive waste disposal at the LLWR within a draft decision document, supported by a draft permit. We will consult on this draft decision before reaching a final decision and varying the environmental permit for the LLWR.

Contents

1. Introduction

1.1. Introduction

The Environment Agency is responsible for regulating the disposal of radioactive waste in England under 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 the environmental permits we issue for disposing 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 main facility for disposing of solid low level radioactive waste (LLW). Following a major review of the 2002 ESCs 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 carried out a rigorous and extensive technical review of this ESC using suitably qualified and experienced personnel.

The aims of the review were to:

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

1.2. Background

The LLWR is located near the village of Drigg in west Cumbria. Radioactive waste was first disposed of at the site in 1959 when United Kingdom Atomic Energy Authority (UKAEA) managed the facility. The site occupies around 100 hectares and waste disposal operations take place in the 40 hectares at the north of the site. In the early days of waste disposal, solid LLW was tipped and buried in shallow trenches. This was similar to contemporaneous practice in the landfill industry. Between 1959 and 1995, approximately 800,000 m^3 of waste was disposed of in 7 trenches. These trenches are now covered by an interim cap, which incorporates a plastic membrane to minimise the amount of water getting in.

In 1986 the House of Commons Environment Committee published a report on radioactive waste (House of Commons 1986). In response to the report’s recommendations, the LLWR operator at the time, British Nuclear Fuels plc (BNFL), made major changes to disposal operations. Disposing of waste in containers placed in an engineered concrete vault (Vault 8) began in 1988, although trench disposals were not completely phased out until 1995. Where possible, this waste is compacted before being packed into freight containers that conform to published standards of the International Standards Organization (ISO). These are referred to as 'ISO freight containers'. The waste in the full containers is then filled with cement grout before being placed in the vault. Non-compactable waste is placed directly into the container and then grouted. Vault 8 has a total capacity of 200,000 m^3 of packaged waste and is virtually full (assuming the containers are not stacked higher). The current operator of the LLWR, LLW Repository Ltd, has recently built another vault (Vault 9), which, at the time of writing, is only used for storing waste. LLW Repository Ltd plans to build further vaults in the future to accept more waste, subject to receiving planning permission from Cumbria County Council and an environmental permit from us.

Figure 1 Aerial view of the LLWR in March 2011 viewed from the north-west (photograph courtesy of LLW Repository Ltd)

We authorised disposal of LLW into the trenches and Vault 8 under RSA 93. In 1999, we started a review of the RSA 93 authorisation for the LLWR. The operator at that time, BNFL, had not updated the impact assessment carried out in the 1980s by the National Radiological Protection Board (NRPB, currently part of the Public Health England (PHE)). Therefore, we could not assess the potential impact of the site from existing and future (predicted) disposals. Consequently, in January 2000 we varied (changed) the LLWR authorisation and required BNFL to provide information about the environmental safety of the LLWR during its operational lifetime (the operational environmental safety case (OESC)) and after its final closure (the post-closure safety case (PCSC)). BNFL submitted these two ESCs in September 2002 (BNFL 2002a and 2002b). Between 2002 and 2005 we carried out a detailed assessment of the safety cases (Environment Agency, 2005a). This raised a number of queries, many of which we recorded in issue assessment forms (IAFs[1]).

Following our review of the 2002 ESCs, we reviewed the RSA 93 authorisation and, in May 2006, granted a new one (Environment Agency 2006a) to the operator, which at that time was British Nuclear Group Sellafield Limited (BNGSL). As well as the ESCs submitted by BNFL in 2002, this authorisation review also took account of the legislation and guidance in effect at the time (RSA 93, and the UK environment agencies' guidance on requirements for authorisation (GRA), Environment Agency et al. 1997). During our authorisation review we had found a number of concerns regarding the 2002 ESC. As a result, we only authorised disposals to Vault 8 and required the operator to provide an updated ESC by May 2011. Our review findings and decisions are documented in a set of reports (Environment Agency 2005a; Galson Sciences Ltd and Environment Agency 2004/5; Environment Agency 2005b, 2006b).

The Nuclear Decommissioning Authority (NDA) now owns the LLWR site and it is operated on behalf of the NDA by a site licence company (SLC). The SLC was initially BNGSL, but we

[1] Issue assessment forms (IAFs) are detailed records of matters raised as part of the Environment Agency's review of BNFL's 2002 ESCs. They record issues that we expected the operator of the LLWR to address before submitting the 2011 ESC.

transferred our authorisation in 2007 to a new SLC, LLW Repository Ltd, with no major changes to the authorisation. This change in SLC allowed the NDA to open the operation of the site up to competitive tender. In 2008, United Kingdom Nuclear Waste Management Ltd (UKNWM) was awarded a contract from the NDA to manage and operate the LLWR. Shares in the SLC were transferred to UKNWM on 1 April 2008 and the SLC continues to be known as LLW Repository Ltd.

From 6 April 2010, the provisions of RSA 93 were incorporated into EPR10. Any future authorisation for LLW disposal at the LLWR will, therefore, be granted in the form of an environmental permit issued under EPR10.

EPR10 also now includes provisions from the Groundwater (England and Wales) Regulations 2009, which bring radioactive substances into the scope of groundwater protection legislation. In applying these aspects of EPR10, we have taken account of our supplementary guidance to the GRA related to implementing the European Union Groundwater Directive (2006/118/EEC) (Environment Agency 2012).

LLW Repository Ltd is currently permitted to dispose of solid low level radioactive waste in Vault 8 of the LLWR and to discharge from the site gaseous and liquid effluents associated with its LLW disposal operations. LLW Repository Ltd has planning permission to store but not dispose of LLW in Vault 9.

In Schedule 9 of LLW Repository Ltd's current environmental permit we set a number of legal requirements for the operator to carry out improvements or provide us with extra information by specific dates (for example, reviews of best practice and establishing a research and development programme). LLW Repository Ltd has now met all the Schedule 9 Requirements, although it needs to continue to report to us annually on some.

Requirement 6 states that, by 1 May 2011, the operator must 'update the Environmental Safety Case(s) for the site covering the period up to withdrawal of control and thereafter.' We required this update to address our criticisms of the 2002 ESCs and supporting programmes (Environment Agency, 2005a, 2005b, 2006b). It must also take account of developments since the 2002 ESCs were produced. These include changes in operating practices, extra information about the site, the design of the repository and the waste inventory, changes in ownership and developments in legislation (particularly EPR10), government policy (Defra 2007), strategy (NDA 2010) and regulatory guidance (Environment Agency et al. 2009).

Since 2006, we have communicated regularly with LLW Repository Ltd about its progress towards meeting the Schedule 9 requirements. The information in LLW Repository Ltd's responses has provided some indication of progress in updating the ESC and served as milestones for assessing progress towards the 2011 deadline for submission. In particular, Requirement 2, which stated that the operator, by 1 May 2008, 'must provide the Agency with a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events (for example coastal erosion and glaciation) and potential future human action'. We carried out a detailed review of the Requirement 2 submission (Environment Agency 2009a to e) and made prioritised recommendations to LLW Repository Ltd on what we would expect it to provide in the 2011 ESC. Our communications with the company since that review focused particularly on the issues covered by higher priority recommendations. We have also reviewed LLW Repository Ltd's position on its progress in addressing the outstanding issues produced by our review of the 2002 ESCs.

The 2011 ESC defines and covers a reference disposal area (RDA), which includes the trenches, the existing Vaults 8 and 9 and future vaults up to Vault 14. LLW Repository Ltd has also defined an extended disposal area (EDA), which includes the RDA plus an extra 6 vaults (Vaults 15 to 20) located to the south of the RDA. A separate assessment of the EDA was included in the 2011 ESC submission, but not fully integrated into the overall ESC.

On 28 October 2013 LLW Repository Ltd made an application to the Environment Agency to vary its existing environmental permit under the EPR10 to dispose of more waste at the repository. This

application covered the EDA, which would allow enough capacity for the LLWR to accept a significant proportion of the UK's LLW predicted to be generated up 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 May 2011 ESC, incorporating any subsequent modifications since that 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.

1.3. Objectives of our review

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 meet when it applies to us for a permit to operate this type of facility. It includes our radiological protection requirements and provides guidance on the nature of the ESC we would expect to see.

Our review provides a technical basis for our decision on LLW Repository Ltd's 2013 application to vary its environmental permit. We will only permit further disposals at the LLWR if the ESC can show 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 impacts on the environment from past and proposed future disposals, taken together, will be acceptable.

1.4. The 2011 ESC submission

LLW Repository Ltd submitted the 2011 LLWR ESC to the Environment Agency on 1 May 2011. The 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 summarising the main arguments and supporting evidence
- Level 2 - 16 topic reports with more detailed evidence in support of the main arguments
- Key Level 3 - 95 supporting reports identified by LLW Repository Ltd as being 'key'
- Other Level 3 - Hundreds of 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 NDA and 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 only covered 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 in October 2013. Any subsequent proposals to change the basis of the 2011 ESC will be addressed separately.

1.5. ESC review reports

From our review of the 2011 ESC we have produced a series of reports that will provide the technical basis for future permitting decisions. These are shown in Figure 2.

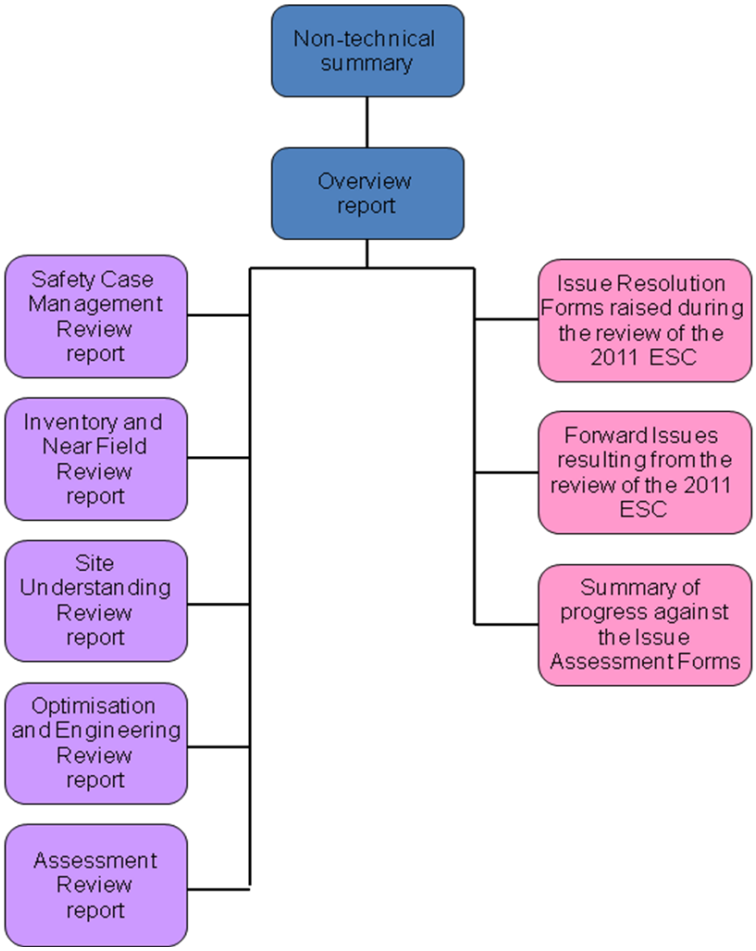

Figure 2 Environment Agency review of the 2011 ESC: document structure

The main document is the overview report of the technical review (this report). 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.

This overview report is supported by 5 technical review reports. These give 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: Safety case management (Environment Agency 2015a); Inventory and near field (Environment Agency 2015b); Site understanding (Environment Agency 2015c); Optimisation and engineering (Environment Agency 2015d); and Assessments (Environment Agency 2015e). The issue resolution forms (IRFs), which give details of specific queries and issues raised during our review, as discussed further in section 2.4, are collated in a standalone report (Environment Agency 2015f).

Forward issues (FIs) 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.

The IAF report comprises our review of LLW Repository Ltd's progress in addressing actions raised in the IAFs produced by our review of the 2002 ESCs (Environment Agency 2015h).

We have also prepared a non-technical summary to the review (Environment Agency 2015i).

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

We welcome any comments on our findings, in particular relating to our forthcoming consultation on permitting the LLWR.

2. The review process

2.1. Approach

We have carried out a detailed technical review of the 2011 ESC, led by our Nuclear Waste Assessment team (NWAT) in consultation with our LLWR site nuclear regulator. The review team included suitably qualified and experienced Environment Agency staff supported by appropriate subject area experts. The review assessed whether the 2011 ESC arguments, which are outlined in the Level 1 report, adequately meet the requirements of the GRA and whether the evidence provided supports the arguments.

We reviewed evidence and supporting information, judged by our suitably qualified and experienced reviewers to be of importance to the 2011 ESC, to the depth considered necessary to determine their validity, including tracing data and assumptions back to original empirical evidence. We looked at other lines of evidence and underpinning information considered to be of lower importance in less depth. We carried out a detailed review of the Level 1, Level 2 and key Level 3 documents. We also referred to other Level 3 documents to the extent that they support the 2011 ESC, together with other documents and further information provided by LLW Repository Ltd up to the date of the application to vary the environmental permit in October 2013.

Since 2006, we have attended monthly liaison meetings with LLW Repository Ltd to discuss progress towards the 2011 ESC. We have also held workshops on specific technical topics as well as carrying out audits on important topics. Since our review of the Requirement 2 submissions (Environment Agency 2009a to e), our communication with LLW Repository Ltd has focused particularly on the issues covered by our higher priority recommendations. As a result of our regular contact, we gained confidence that the 2011 ESC would broadly meet our expectations and reduced our uncertainty about its contents and suitability. It also allowed us to review material that was used in the final submission.

We consider that our approach to the review provided a proportionate risk based solution, within reasonable timescales and costs. It also took into account our confidence in LLW Repository Ltd's approach to developing the 2011 ESC gained through regular discussions with the company over recent years.

We note that LLW Repository Ltd used an independent peer review group, made up of a number of suitably qualified and experienced technical specialists, to review the 2011 ESC development programme and outputs. This is in line with the requirements of the GRA, which state that 'Peer review is important both to quality management and to the application of sound science and good engineering practice' (Environment Agency et al. 2009). The group was asked to review information and reports prepared in the period leading up to the Requirement 2 submission in May 2008 (Bennett et al. 2008). It was also asked to review the activities and reports leading up to issue of the 2011 ESC, including two rounds of review of the developing 2011 ESC reports and a review of the final as submitted versions of the 2011 ESC reports (Bennett et al. 2011). This allowed LLW Repository Ltd to take into account peer review team comments on the developing safety case. An international peer review of the safety case approach was also commissioned (McCall 2010). In our review of the 2011 ESC we have taken the peer review and LLW Repository Ltd's responses into consideration (Baker 2012).

2.2. Review groups

Review of the 2011 ESC was organised around four themes or areas to focus the right expertise on the right parts of the ESC (Inventory and near field; Site understanding; Optimisation and engineering; Assessments). A specialist review group was set up to cover each of these areas. Each review group was managed by a member of NWAT, with other members taken, as necessary, from NWAT, other parts of our Nuclear Regulation Group and Radioactive Substances Regulation, the wider Environment Agency and specialists outside the Environment Agency selected to cover the relevant range of technical topics.

Figure 3 shows the structure of the review team. Each review group reviewed the documents in its area(s) (see purple boxes). The Safety case management group also co-ordinated the technical review and reviewed documents relevant to management arrangements and how LLW Repository Ltd addressed the requirements of the GRA. The review groups reported to a Project Board, which dealt mainly with higher level issues, the direction of the review, the overall conduct of the review and the performance of the project. A Project Working Group was also set up to oversee day-to-day project management issues, liaising with the Project Board and the Safety case management group.

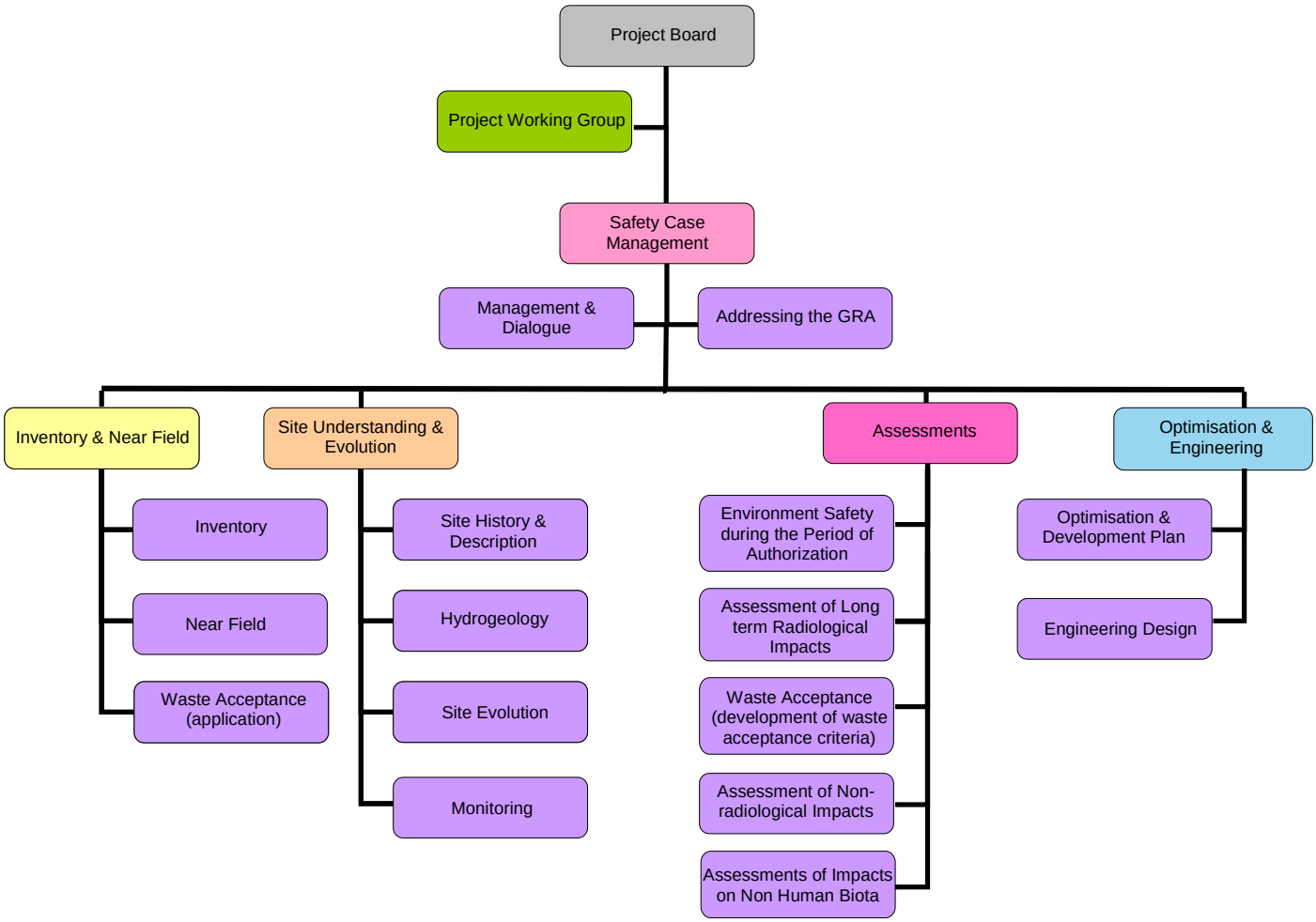

Figure 3 Main focus areas of the 2011 ESC review groups

2.3. Review process

The 2011 ESC review was carried out in four stages:

1. Preparatory work before the submission (up to May 2011).
2. Initial review of ESC documents (May 2011 to July 2011). An initial top down review of the ESC documentation to establish priorities and any significant issues. Initial feedback was provided to LLW Repository Ltd in July 2011.
3. Detailed review of the ESC documentation (August 2011 to October 2013). This included a detailed technical review of the Level 2 and 3 documents and targeted audits. Throughout this process we asked LLW Repository Ltd for further information which it provided to us. Our review considered LLW Repository Ltd's responses to our requests for further information as well as further technical work the company carried out as part of its ongoing maintenance of the ESC up to October 2013.

4. Preparing and documenting the review conclusions.

We provided feedback to LLW Repository Ltd on our findings to inform its permit application for further disposal at the site.

Throughout the review period the review team was engaged in detailed investigations to improve our regulatory understanding of the 2011 ESC. This included internal consultation and communication with LLW Repository Ltd to clarify any uncertainty. Important parts of this investigation are included in the IRFs.

We reviewed the use of computer models in the 2011 ESC. This involved considering model selection and input and output data. We also audited the quality management systems under which computer modelling was carried out. We did not attempt to replicate any model output.

2.4. Review format

The main test of the adequacy of the 2011 ESC was whether it met Schedule 9 Requirement 6 of the current site permit and satisfied the relevant principles, requirements and guidance in the GRA. The 2011 ESC also had to demonstrate that it applied sound science and engineering and used substantiated evidence to demonstrate safety to people and the environment. We considered a number of more general questions that summarise what we expect from an ESC ('sufficiently' and 'adequately' used here mean 'consistent with their importance to the environmental safety case'):

- Are the arguments, descriptions and explanations in the ESC sufficiently clear, coherent and internally consistent?
- Are all significant claims and assumptions in the ESC, including data used in quantitative analyses, adequately substantiated by traceable, clear, relevant and sufficiently complete evidence?
- Where available information is incomplete or unreliable, has LLW Repository Ltd taken appropriate action to make sure that the current ESC is reliable and to obtain better information for the future?
- Are the measures described in the ESC, including the content of the case itself, proportionate in view of the hazard posed by the waste disposed of, or to be disposed of, in the LLWR?
- Are uncertainties systematically identified and adequately addressed in ways appropriate to their nature and significance?
- Are links between measures and assumptions affecting different parts of the ESC and LLWR operations systematically identified and adequately addressed?
- Do the arguments, descriptions and explanations presented indicate that LLW Repository Ltd adequately understands the LLWR site, the disposal system and its behaviour?
- Do the arguments, descriptions and explanations presented indicate that LLW Repository Ltd has adequate control over the management of the LLWR site?
- Do the quality of the ESC documents and the descriptions of work done and measures taken indicate that quality is adequately assured in LLW Repository Ltd’s activities?
- Has LLW Repository Ltd adequately explained any significant differences between the results and conclusions of the 2011 ESC and the 2002 ESCs?

Similarly, when reviewing quantitative assessments within the 2011 ESC, particularly those aimed at demonstrating compliance with GRA Requirements relating to site impacts, reviewers considered the following questions about the overall assessment approach and methodology. These are based on guidance from the International Atomic Energy Agency (IAEA) on safety assessments for near-surface disposal facilities (IAEA 2004):

- Is the assessment context adequately defined and substantiated, including the purpose of the assessment, its regulatory relevance, the end-points to be assessed, the overall assessment approach (for example realistic or cautious, generic or site-specific), the characteristics of the disposal system and the assessment timeframes?

- Is convincing evidence provided that the range of scenarios/cases assessed adequately cover the range of possible real situations in which impacts might arise within the defined timeframe of assessment?
- For each scenario/case, is there a clear definition of the range of actual situations for which it is intended to be representative or bounding?
- Are the important characteristics of the scenarios/cases to be modelled adequately defined and substantiated?
- Are all relevant sources, pathways and receptors identified and adequately defined for each scenario/case?
- Have the objectives of modelling been defined and substantiated, with reference to the assessment context and the real disposal system?
- Do the models used adequately represent a sufficiently comprehensive set of features, events and processes and the interactions between them, to satisfy the modelling objectives?
- Is the range of applicability adequately defined and substantiated for each model used and have models been used only to represent conditions that are within their demonstrated range of applicability?
- Have all data used been derived in a manner consistent with the model(s) in which they are used?
- Have model and data uncertainties been systematically identified and adequately addressed in ways appropriate to their nature and significance?
- Is the sensitivity of modelling results to significant assumptions adequately demonstrated?
- Are modelling results reported and used in ways that adequately take account of the uncertainties in those results?

Where potential deficiencies or other issues were identified during our review of the 2011 ESC, 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 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). 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. We asked, but did not require, LLW Repository Ltd to provide responses to these to enable us to conclude our review of the ESC. However, LLW Repository Ltd did provide responses whenever requests for further information were made.

For each RI, RO and TQ we generated an issue resolution form (IRF) to record and track the issue and its resolution. Similar to IAFs, IRFs are detailed records of concerns raised as part of our review of the 2011 ESC. Each IRF includes one or more actions. We expected LLW Repository Ltd to respond to the action(s) specified on the IRF by a specified date(s).

The IRFs form a substantial part of the results of our review. 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 documents. Each IRF also records our evaluation of the response. An issue has only been closed 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.

The IRFs are not sequentially numbered. This is because some IRFs were identified as possible queries but not issued, as they were addressed by other means. 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.

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 that we believe will benefit from further work, development or clarification in the future. We call these areas 'forward issues' (FIs). These are areas of work that we believe it is important for LLW Repository Ltd to progress as part of its forward improvement plan. We require LLW Repository Ltd to engage with us on these FIs, to put in place methods 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 expect the outcome of FIs to be considered within updates to the 2011 ESC.

Throughout the review, we also made a number of specific recommendations to LLW Repository Ltd. These recommendations cover areas where we see scope for possible improvement or development, but which are relatively minor compared to FIs. We expect LLW Repository Ltd to track and address these recommendations.

However, it is important to note that these FIs and recommendations do not represent the only areas of work that we expect LLW Repository Ltd to progress and are not intended to represent a comprehensive scope for forward work. We 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.

We have completed a detailed review of the 2011 ESC against all the GRA requirements. However, our review reports do not document all aspects of this review, as this would be unnecessarily detailed and long. Therefore, this and our other reports summarise the scope and general results of our review, showing higher level conclusions and summaries. We go into more detail where we have focused on specific areas of regulatory interest, have had to request and review further information or have identified scope for future improvements. As a result, the scope of our reports focus 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 there are examples of good practice.

3. Our review

3.1. Overview

The LLWR is located approximately 400 metres from the coast at its nearest point. LLW Repository Ltd predicts that it is almost certain that the LLWR will be destroyed by coastal erosion commencing on a timescale of a few hundred to a few thousand years. It predicts the vaults and trenches will be completely eroded within 1 thousand to a few thousand years. The company has based the 2011 ESC on this assumption although it does explore implications on site impacts should erosion be delayed beyond a few thousand years.

Because of the nature of radioactive waste, the hazard will remain for many thousands of years after it has been disposed of. In line with our GRA, the 2011 ESC covers the period of authorisation of the site, including waste disposal, closure of the facility, emplacement of post-closure engineering and active monitoring and surveillance and the post-closure period[2]. The 2011 ESC takes no credit for active controls on the site after the period of authorisation and it assumes there are no restrictions on site access.

We consider that the 2011 ESC is generally a well-written submission and is an improvement on the 2002 ESCs. The quality of the technical work supporting the ESC was of a high standard and covered all those areas that we would expect the ESC to address. However, in a number of areas we felt that the Level 1, 2 and key Level 3 documents did not make the case on their own and so we needed to ask for extra documents during our review. Because many Level 3 documents were written by contractor organisations, there was a great deal of repetition between them and a loss of clarity where information in an older document had been superseded. We note that the majority of documents were dated 2011, although some of them had been prepared earlier and, therefore, it was not always obvious where information was the latest available.

LLW Repository Ltd has generally directly addressed GRA requirements with evidence, as summarised in the Level 2 document on ‘Addressing the GRA' (LLW Repository Ltd 2011a). Further supporting evidence has been traceable, although we have had to refer to information not included within the original submission.

We consider that the 2011 ESC, along with technical work carried out afterwards has given us enough information to assess whether the company has adequately met the principles and requirements of the GRA and Schedule 9 Requirement 6 of the current LLWR environmental permit, and to support our decision on the future permitting of the LLWR.

The following sections provide a summary of the main findings from each of our review groups.

3.2. Safety case management

The safety case management review group reviewed a wide range of topics related to how LLW Repository Ltd developed and presented the 2011 ESC, managed its production and implementation, addressed some of the broader technical issues, considered further improvements and worked with others to do this. Our assessment focused on the main Level 1 report (LLW Repository Ltd 2011b) and the Management and dialogue report (LLW Repository Ltd 2011c) and a number of the references therein. However, we also considered a number of broader issues presented in the Level 2 and Level 3 reports, as well as the presentation and clarity of the 2011 ESC as a whole.

We consider the overall quality of the 2011 ESC in the area of safety case management is good. The structure of the ESC and clarity of arguments is generally clear and coherent, with good referencing to supporting reports.

[2] Management and regulatory control of the LLWR will stop at site closure.

We are satisfied that LLW Repository Ltd has engaged effectively with us and others when developing the 2011 ESC and has taken the GRA guidance on following a 'process by agreement' (Requirement R1) into account in formulating their engagement with us and others. We were provided with documents at relevant stages in the process. LLW Repository Ltd defined and agreed the processes and timing of future reviews of the ESC with us.

We sought further clarity and wider engagement from LLW Repository Ltd on its stakeholder engagement during the 2011 ESC production and review process. Having received a response to this request, we are satisfied that LLW Repository Ltd has met the expectations within the GRA (Requirement R2) regarding speaking with local communities and others and has allowed for flexible, early, ongoing, open and inclusive engagement that encouraged 'challenge' from a wide range of relevant interested groups. We are satisfied that the process facilitated our involvement. We support LLW Repository Ltd's commitment to liaise with others and the importance it gives to this area of work.

We consider that LLW Repository Ltd has presented an adequate and proportionate ESC in line with the GRA (Requirement R3). We welcome the integrated approach the company has used to evaluate the environmental performance of the site. We note that there are some inconsistencies between the assessment models used for the period of authorisation and post-closure assessment period. However, these are not significant and can be addressed in future updates to the ESC.

We raised a number of requests to further understand the information provided within the 2011 ESC covering the environmental safety culture and the expectations of LLW Repository Ltd's management systems (GRA Requirement R4). With this additional information, we conclude that LLW Repository Ltd operates with a positive environmental safety culture and has a suitable management system in place. However, we have identified a number of areas where there is scope for continued development. This positive environmental safety culture is demonstrated through LLW Repository Ltd's policies, processes, approaches, communication activities, provision of environmental resource and scrutiny from the LLW Repository Ltd Board of Directors.

We are reassured that LLW Repository Ltd’s management system is well established and mature, having developed over a number of years with oversight from us. Overall, we consider the management systems to be comprehensive, fully integrated and clearly documented. We support the fact that the company put specific project management arrangements in place when it was developing the 2011 ESC. These included a dedicated project team, project manager, project execution plan and other quality, peer review and engagement procedures.

We paid particular attention in our review to LLW Repository Ltd's plans for future ESC related resources, competency, knowledge and succession planning. We also looked at how the company manages ESC records, given their importance in effectively managing, implementing and maintaining the ESC. We are reassured that GRA expectations are adequately met by a number of ongoing measures to improve the ESC Project Team and to make sure that all ESC records are effectively captured. However, we have identified several areas for improvement, including the need to develop a new low level waste tracking system that meets the needs of the current 2011 ESC, the waste acceptance criteria and the environmental permit, as well as making sure that all ESC-related records are actively managed.

We also consider independent peer review to be an important part of developing a sound and reliable ESC. We welcome the use of both a UK based independent peer review group and an international peer review group process.

As well as specific GRA requirements, our review also addressed a number of broader issues relevant to producing an ESC. These included presentation, approach, safety functions, managing uncertainties, forward programmes of work, waste acceptance criteria, capacity management and implementing the ESC. We are satisfied, after further information was provided, that each of these areas has been adequately addressed and that LLW Repository Ltd has demonstrated that GRA requirements have been met.

However, we identified and highlighted a number of areas with scope for improvement, including, but not limited to:

- better use of audit trails within the ESC reports

- scope for relying less on models and giving more emphasis on alternative lines of argument such as increased use of monitoring, experimental or analogue data
- providing clearer safety arguments and developing safety function approaches further
- developing methods for updating and for managing elicited values used in the 2011 ESC
- developing a more systematic approach to addressing uncertainties
- capturing learning from the 2011 ESC and previous ESCs within a forward programme of work
- presenting assessments related to the EDA in a more integrated way

We are satisfied that the proposed changes to the LLWR waste acceptance criteria (WAC) are consistent with the assumptions made in the 2011 ESC and subsequent updates. We consider these will be enough to prevent unacceptable doses and risks to people and the environment. A 'sum of fractions' approach to managing radiological capacity over the lifetime of the site has been proposed. This approach is recommended by the IAEA to account for additivity of the impacts from different radionuclides (IAEA 2003). We believe this has been appropriately implemented within the WAC. We welcome further controls proposed on higher activity particulate materials and discrete items[3], which we required LLW Repository Ltd to consider the need for and which we believe are appropriate.

We are satisfied that LLW Repository Ltd has put in place adequate plans to implement the WAC and associated procedures. LLW Repository Ltd must also effectively implement broader aspects of the 2011 ESC on site, such as change control procedures, operational procedures and tools, addressing stored waste and engineering development. We are satisfied that LLW Repository Ltd has demonstrated it will meet these requirements.

3.3. Inventory and near field

The inventory and near field review group assessed those parts of the 2011 ESC that related to the amounts and character of past and potential future disposals and how disposed waste in the repository changes over time. The overall quality of the ESC submission in these areas is high. The technical work is of a high standard and has been well documented. The clarity of the safety arguments was adequate and the supporting information can be traced back to the source documents.

Summaries of our main findings in the inventory and near field areas are provided in the following sub-sections.

3.3.1. Inventory

LLW Repository Ltd (2011d) describes its work to improve the understanding of the existing and future inventory of waste disposed of in the LLWR. It also presents LLW Repository Ltd's current 'best estimate' of the inventory. We reviewed further information in a number of Level 3 documents, including Wareing et al. (2008), Baston et al. (2011), Harper (2011a, 2011b, 2011c), Dickinson and Smith (2011) and Dickinson and Kelly (2011).

LLW Repository Ltd assessed the inventory in 4 distinct areas: past disposals to the trenches; past disposals to Vault 8; future disposals to Vault 8 and future vaults; and the non-radiological inventory.

For the trench disposals, LLW Repository Ltd carried out a major programme of work to review all the significant sources of documentary evidence. It used this to identify as accurately as possible not only what waste is in the trenches, but also where specifically in the trenches particular waste streams or radionuclides (particularly those that contribute most to the long-term risks from the site) are concentrated. LLW Repository Ltd also commissioned interviews with past and present staff at the LLWR and the Sellafield site to identify any waste that may have been disposed of at

[3] A discrete item is a distinct item of waste that, by it characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling/re-use of materials should the waste item be exposed after repository closure.

the facility without accurate records being kept. This provided evidence that the derived trench inventory is generally appropriate. However, some discrete items, individually containing significant levels of radioactivity, may have been disposed of in the trenches and not accurately recorded within the inventory records. LLW Repository Ltd provided evidence that these disposals were not widespread enough to significantly affect the overall assessment of impacts or results of the 2011 ESC. We have raised an FI requesting that, before the final cap is installed, LLW Repository Ltd further reviews past disposals of discrete items, assesses the possible implications and identifies any action needed.

We consider that LLW Repository Ltd has made good use of the available information to derive the trench inventory and that the company's understanding of the trench inventory has improved significantly since the 2002 PCSC was issued. LLW Repository Ltd acknowledges that there is still significant uncertainty associated with the trench inventory, estimating that uncertainty to be in the region of an order of magnitude. We accept that this is inevitable because of the nature of the past disposals. LLW Repository Ltd has assessed the implications of this appropriately in its safety assessment. However, LLW Repository Ltd must continue to update the inventory for the trenches by assessing future waste radionuclide fingerprints and evaluating whether these present a better match for past disposals, along with any other readily available information.

The inventory for Vault 8 used in the 2011 ESC includes waste disposed of to the vault between 1988 and March 2008. Some of the future inventory will also be disposed of in Vault 8. The derived inventory of waste disposed of in Vault 8 is significantly less uncertain than that for past disposals to the trenches, because the records are better for this period. We note that there is limited information on the distribution of waste across Vault 8 in the 2011 ESC. Since the submission of the 2011 ESC, LLW Repository Ltd produced spatial distribution maps for stack settlement potential (Penfold et al 2013), which provided useful information that was used in the assessment of cap settlement potential. We expect the further use of spatial distribution maps to support the assessment of important aspects of safety, where they can support particular technical or safety arguments, similar to those produced for the trench disposals. We have raised this as an FI to be addressed in future updates of the ESC. This will improve understanding of the distribution of radionuclides and materials in Vault 8 to help future projections of the evolution of the near field and cap performance and to support the use of emplacement strategies.

The 2011 ESC also provided limited information about the disposal of non-standard packages in Vault 8. We shall expect more complete information in future submissions. As with the trenches, we also expect LLW Repository Ltd to review past disposals of discrete items to Vault 8, assess the possible implications and identify any action needed. We have made several recommendations for improving the representation of the inventory in Vault 8 in future assessments. These include using future waste radionuclide fingerprints to improve the inventory of comparable waste streams disposed of to Vault 8.

LLW Repository Ltd has made substantial progress in understanding the forward inventory for potential disposals to the LLWR. This has given us confidence that LLW Repository Ltd understands which waste streams would contribute significantly to the presence of important radionuclides. LLW Repository Ltd also appears aware of those future waste streams that have the greatest uncertainty associated with them, including the nature and timing of future waste arisings (acknowledging that this will be determined by external factors). We consider that the derived forward inventory of waste to be disposed of to the LLWR is adequate for the present purpose. We support LLW Repository Ltd's continuing liaison with the NDA and waste consigners (companies sending waste for disposal) to improve the accuracy of the forward inventory.

Overall, we consider that the radionuclide inventory collated in the 2011 ESC provides suitable source information (source term) for the radiological assessment calculations carried out. Estimates of uncertainty in the radionuclide inventory and alternative inventory scenarios defined to account for variations in the forward inventory appear reasonable.

LLW Repository Ltd uses the LLW Tracking System (LLWTS) to record the composition of each waste disposal to the LLWR and to track the position of containers in the vaults. At present, the database provides a good system for recording this information. However, we have recommended a number of improvements to the system. In particular, we want LLW Repository Ltd to reassure

us either that the LLWTS is a suitable tool to enable the company to manage the emplacement strategies proposed in the 2011 ESC or that it will implement an alternative system. The tracking system should be able to record and allow important waste information critical to the ESC, such as the amount of voidage (unfilled space) in containers and radionuclide content, to be used effectively.

LLW Repository Ltd has made a good start in deriving data for the non-radioactive composition of the waste inventory, but it needs to do further work in this area. In particular, we consider that the information about the non-radiological part of the trench disposal inventory is poor, reflecting the age of waste and contemporary practices. LLW Repository Ltd acknowledges this uncertainty and that it will need to continue to take account of this in groundwater impact assessments and monitoring programmes if it is not possible to reduce that uncertainty further. We accept information available is limited and support LLW Repository Ltd's liaison with waste consigners and the NDA to understand more about the non-radiological part of disposals in the future. To demonstrate it is still protecting groundwater, we require LLW Repository Ltd to produce an updated non-radiological hydrogeological risk assessment before the end of 2017. We also expect to see, as far as possible, a better underpinned non-radiological source term used in this assessment.

In summary, we consider that LLW Repository Ltd has made good use of the information available about the waste inventory. We consider that the radionuclide inventory in the 2011 ESC provides a suitable source term for the radiological and non-radiological assessment calculations. Estimates of uncertainty in the radionuclide inventory and alternative inventory scenarios defined to account for variations in the forward inventory appear reasonable. LLW Repository Ltd has assessed the effects of this uncertainty, including alternative inventory scenarios, in the radiological safety assessment. We have raised two FIs that relate to the waste inventory and have made a number of recommendations to LLW Repository Ltd to make sure that inventory information continues to support the ESC appropriately in the future.

3.3.2. Near field

The near field consists of the waste and engineered barriers and relevant processes therein.

LLW Repository Ltd has carried out a substantial programme of work to better characterise the waste and waste forms and to determine the implications for the evolution of the near field. Consequently, its understanding has improved significantly since the 2002 PCSC. This work is presented in LLW Repository Ltd (2011e). However, there was not enough detail in this document for us to assess the 2011 ESC arguments fully. We had to review Level 3 documents and ask for documents not included in the original 2011 ESC submission to get enough information for our assessment. These supporting documents include Small et al. (2011a, 2011b, 2011c). We also reviewed the results from several programmes of work LLW Repository Ltd carried out after it submitted the 2011 ESC either as a direct result of queries raised by us or arising from its ongoing work programme (for example, LLW Repository Ltd 2013a, Penfold et al. 2013; Small et al. 2013, Smith and Jackson 2013; Sumerling 2013a; and Taylor and Baker 2013).

The biogeochemical evolution of the near field plays a significant role in determining the concentrations of radioactive and non-radioactive contaminants that will be released from the near field over time. LLW Repository Ltd developed a detailed quantitative model of the repository near field to underpin a conceptual understanding using its Generalised Repository Model (GRM)[4]. We consider that LLW Repository Ltd has identified and characterised the main factors that could affect the biogeochemical evolution of the near field, resulting in a good understanding of how the chemistry of the near field will evolve over the lifetime of the facility. In particular, LLW Repository Ltd has reviewed the implications of a number of factors that play significant roles in determining the concentrations of radioactive and non-radioactive contaminants that will be released from the near field. These include maintaining hyperalkaline conditions in the vaults, which will restrict the

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

release of contaminants into the wider environment and assessing the implications of colloids and complexants, which could enhance the transport of contaminants from the near field.

Understanding the behaviour of carbon-14 (C-14) in the near field is particularly important, because it may migrate from the repository through entrainment in gas (such as methane and carbon dioxide) generated from the waste and, in a dissolved form, via groundwater. There is a significant future inventory of C-14, mostly associated with reactor decommissioning waste. LLW Repository Ltd needs to understand how this waste behaves so it can determine its acceptability for disposal to the LLWR. The company has carried out significant work to better understand the partitioning of C-14 in the near field between the aqueous and gas phases. After the submission of the 2011 ESC, LLW Repository Ltd re-assessed its understanding of the release of C-14 via the gas pathway, as the case submitted was based on an overly conservative model. This projected that the radiological risk guidance level would be exceeded after the end of the period of authorisation. To resolve this, LLW Repository Ltd carried out further calculations based on more realistic assumptions, including further characterisation of C-14 release processes at the waste container scale. We have reviewed this additional assessment and are satisfied that it is more realistic and appropriate than the original assessment. Updated risk projections were below the risk guidance level. We expect LLW Repository Ltd to continue to improve its understanding of the behaviour of C-14 including, in particular, the chemical form of C-14 in the various waste forms. We have recommended the GRM, or a future alternative near field model, is further validated through experimental work with regard to C-14 release under conditions more representative of the LLWR. This is likely to form part of a wider forward investigation programme into the behaviour of C-14.

Understanding of the evolution of the physical properties of the near field is closely linked with repository engineering and the integrity of the barrier systems. During a site visit in 2011 to inspect container corrosion, we observed that some of the ISO freight containers of waste in Vault 8 were in a poor condition. We observed penetrative corrosion of container lids and walls, localised softening of the encapsulating grout, vegetation growing in and on the containers, the presence of water on the containers and the presence of ullage in the waste packages (Environment Agency 2015j). These issues will have an effect on settlement and how the final engineered cap performs. LLW Repository Ltd recognised the significance of these observations and put in place an extensive programme of work to assess and address these issues. Since 2011, the company has:

- carried out work to quantify the potential risk of settlement and demonstrated that it can be adequately managed by cap construction and/or height of ISO freight container stacks
- taken immediate actions to address ullage in future containers, with revised grouting processes being implemented and shown to be effective
- progressed plans to remove vegetation and to address the voidage in certain containers
- began programmes to look at optimising the container design and the protection of containers from the elements in the future

This work was ongoing at the end of our review and we will monitor progress via a number of FIs and through our ongoing regulatory engagement.

Understanding the near field is directly relevant to understanding the evolution of the LLWR and the potential for contaminants to be released from the facility. We conclude that LLW Repository Ltd's understanding of the near field suitably underpins its estimates of environmental impact, its approach to optimisation and its determination of WAC. We have identified a number of areas of good practice, for example using variant cases to investigate the implications of significant uncertainties on the evolution of the near field and the flux of contaminants from the near field. Overall, we are confident from LLW Repository Ltd's assessment that it has a good understanding of the evolution of the near field after the period of authorisation. However, we have also identified a number of areas for further improvement in near field understanding. We have documented these in our FIs or recommendations. Some of the main areas we expect to see addressed and reported in future submissions of the ESC are:

- The company continuing to understand more about the voidage in disposal containers and the grouted waste form, in particular in Vault 8. We expect LLW Repository Ltd to make sure that

the design of the engineered cap, combined with the extent of higher stacking of waste containers, can accommodate any uncertainty in the amount of voidage within the waste mass.

- Implementing relevant procedures or review points to make sure that any future changes to the constituents of waste received at the LLWR from those assessed within the ESC, will not adversely affect the evolution of the near field. For example, changes to its bulk physical or chemical form that may come about as a result of implementing the waste management hierarchy.
- Providing a proportionate monitoring and characterisation programme for colloids and complexants to give more certainty that the conclusions reached in the 2011 ESC remain valid over the period of authorisation.
- Continuing to liaise with waste consigners so that the data used in assessing complexants remain valid for past and future disposals. We also expect LLW Repository Ltd to be aware that there could potentially be other complexants, which may not have been assessed, in disposals to the facility and to assess the potential impacts of these complexants as appropriate.
- Assessing the sensitivity of the outputs from the near field model(s) to the discretisation of the model.

LLW Repository Ltd is using near field information to underpin changes to the WAC. It has introduced further controls to address total potential voidage within waste containers, which take into account concerns we raised as a result of the condition of containers stored in Vault 8. We note that LLW Repository Ltd is continuing to improve communication with consigners to address this and we will encourage further improvements. LLW Repository Ltd has also proposed a change to the WAC to allow complexants. LLW Repository Ltd proposes that disposals of some complexants (for example citrates) need not be limited, other than to prevent bulk disposals of them, whereas certain aminopolycarboxylic acids of which EDTA is the most common can be accepted but disposals must be limited. We have concluded that the case presented supports this change to the WAC. However, to address this matter fully, we have raised an FI to seek further assurance that disposing of complexants will not have unacceptable effects on the environment. We have asked LLW Repository Ltd to set up a proportionate monitoring programme and to continue to liaise with consigners to understand the quantities and type of complexants disposed of now and in the future.

LLW Repository Ltd's future monitoring programme will play a significant role in further enhancing its understanding of the evolution of the near field and in supporting the further development of the near field models. We have raised FIs to make sure that future monitoring addresses several areas where there is uncertainty. This includes, for example, further sampling of complexants in the trenches and monitoring of the cap to establish whether it is performing as predicted.

3.4. Engineering and optimisation

The Environment Agency defines optimisation as 'the principle of ensuring that radiation exposures are as low as reasonably achievable (ALARA) in the given circumstances' (Environment Agency et al. 2009). LLW Repository Ltd has used an optimisation process to determine its preferred approach to the design and operation of the LLWR, as summarised in the optimisation and development plan (LLW Repository Ltd 2011f). The principles of optimisation underpin the development of the reference design for future development and closure of the facility (LLW Repository Ltd 2011g). There is, therefore, a close link between the optimisation process and the development of the engineering design.

The main findings from our review of the engineering and optimisation areas are summarised in the following sub-sections.

3.4.1. Engineering

LLW Repository Ltd presents its site development plan in LLW Repository Ltd (2011f). The site development plan gives 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.

The main components of the future engineered system in the site development plan are:

- Additional engineered vaults, which will eventually fill the northern part of the site. Future vaults will be designed with concrete bases and a low permeability barrier system that will provide a barrier to leachate flow, but with only 1 metre high containing side walls. The future vaults will incorporate engineered passive drainage arrangements that extend below the basal barrier system.
- The grouted ISO freight container waste form, which provides a barrier to contaminant releases and a foundation for constructing the final engineering cap.
- A final cap, which will be designed to minimise infiltration of water and future intrusion of people, plants or animals and to passively vent gas.
- A low permeability cut-off wall dug into the ground surrounding all the waste disposals, which will minimise infiltration and groundwater flow into the waste and minimise lateral migration of any contaminants released from the waste mass.
- Active leachate collection and management throughout the period of authorisation. Leachate will be collected, monitored and discharged to sea via the marine pipeline.
- Applying best available techniques to improve the interim trench cap before the final cap is put in place.

During our initial review of the 2011 ESC we noted that the engineering design presented was, to some extent, conceptual in nature and needed further optimisation and development before it could be implemented. We considered this to be reasonable given the status of the design and the anticipated timescales before the next major phase of construction. As a result, we have carried out a large amount of regulatory scrutiny of and interaction with LLW Repository Ltd during our review of the 2011 ESC, so that we could be confident that the presented design can be built and will behave as predicted, meeting the requirements of the ESC.

At the end of our initial review, we had many detailed questions on the engineering design. Rather than raise a large number of IRFs, we arranged a workshop with LLW Repository Ltd to discuss these issues. The discussions at the workshop provided clarity and addressed many of our questions satisfactorily. We asked LLW Repository Ltd to address our remaining questions and to reassure us that it can address these issues appropriately before implementation, by providing us with a comprehensive engineering forward programme.

In response LLW Repository Ltd submitted to us an engineering forward programme that we have concluded will address the outstanding questions from our review of the 2011 ESC (Shaw 2013). We consider that the engineering forward programme can successfully progress many aspects of the engineering design to the necessary level of detail before construction and will allow an appropriate and optimised repository design to be produced. As well as the forward engineering programme, we expect the company to implement an appropriate forward research and development programme, along with other investigations to provide the necessary design justification for the LLWR engineering systems. We will continue to work with LLW Repository Ltd and will carry out assessments of the engineering design at appropriate stages in the design justification process leading up to and during any future construction.

The 2011 ESC did not include a formal engineering performance assessment. Instead, projections of the performance of the engineered barrier system were based on elicited information to assess engineering performance and take account of uncertainties. We consider that LLW Repository Ltd should make increased use of monitoring, experimental and/or analogue data in future assessments of engineering performance wherever practical and beneficial to do so. For example, the benefits of monitoring engineering performance are illustrated by LLW Repository Ltd's analysis of the performance of the interim trench cap, which includes monitoring of the cap and cut-off wall. This showed that the interim trench cap is performing significantly less well than assumed in the 2011 ESC and LLW Repository Ltd has provided us with details of its programme of work to address this. We expect the company to further consider the effect of potential failure of components of the engineering system on repository performance in future ESCs.

At the end of our review, we were confident that LLW Repository Ltd had developed an appropriate conceptual engineering design. The presented design incorporates systems capable of providing the required safety objectives such as isolation and containment. However, LLW Repository Ltd

must carry out further design substantiation and safety assessment work as the details of the design are developed and, before construction, to demonstrate how these systems would be expected to behave. We expect this work to make effective use of material performance information, geotechnical data and research and development.

We conclude that the engineering design presented within the 2011 ESC is appropriate, meets regulatory requirements and is at an appropriate level of detail at this stage of development of the facility. However, we note that before the future vaults and the closure engineering are built, a substantial programme of work is needed to determine detailed engineering designs and substantiate the performance of the individual components of the engineered system. LLW Repository Ltd's engineering forward programme, as outlined in Shaw (2013), covers the majority of these requirements. We have also made a number of recommendations and raised FIs that cover the main areas where we would like to see improvements ahead of further major engineering developments and future submissions of the ESC. Where they are not already identified, we expect these areas to be included within LLW Repository Ltd's forward programmes of work. The main areas we expect to see addressed are:

- A substantial programme of engineering design and performance analysis before the repository design is finalised and further construction work begins.
- Further development of an optimised cap design, taking full account of all available information on the potential for cap settlement and voidage within the vaults and taking into account the optimisation of waste container stack height.
- Further assessment and substantiation of the final engineered cap, including further design justification of the functional layers of the cap and assessment of potential cap failure mechanisms.
- Container optimisation and assessment of the impact of extended exposure on container integrity to optimise the protection and containment of waste and waste containers during operations whilst exposed and following capping.
- Optimisation of the vault closure engineering.
- Development of a comprehensive gas management strategy.
- Development of a leachate management strategy for the period of authorisation and substantiation of the long-term performance post-closure.

We will monitor progress with the engineering design through to and during construction as part of our ongoing regulation of the site and via our FIs.

3.4.2. Optimisation

LLW Repository Ltd describes its use of an optimisation process to define its approach to design, construction, operation, closure and post-closure arrangements in a series of option studies, as summarised in LLW Repository Ltd (2011g) and Paulley and Egan (2011). The optimisation process has been framed by government's defined role for the LLWR as a national LLW disposal facility (Defra 2007), the environmental context, past decisions taken at the site and the physical constraints of the LLWR site.

LLW Repository Ltd has used the output from these optimisation studies to underpin its decisions on site development. The optimisation process involved gathering the output from a series of optioneering studies addressing different aspects of the disposal system. These studies addressed questions about management options for past disposals, controls for future waste acceptance and the best ways of packaging and conditioning waste for disposal. Other studies addressed controls over the design and operation of the LLWR, including post-closure engineering, waste emplacement strategy and post-closure institutional arrangements.

We consider that LLW Repository Ltd is using optimisation appropriately to inform the development of the repository design, with the methods for generation and assessment of potential options being consistent with good practice and meeting our regulatory expectations. However, documentation of the evolution of the repository design throughout the optimisation process was unclear, which made scrutiny of the optimisation process challenging and unnecessarily difficult. The optimisation process which underpins the proposed repository design was started before the

2002 ESCs. The process of discounting options between 2002 and 2011 was particularly difficult to follow due to the poor documentation. Although we were able to reach a positive conclusion regarding the optimisation process, we expect to see the quality of documentation of the optimisation process significantly improved in future updates to the ESC. We have raised this issue as a recommendation.

Within IRFs we asked for more explanation 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 satisfactorily.

LLW Repository Ltd has investigated the potential to optimise the LLWR in light of the potential for coastal erosion, for example retrieving significant disposals from the trenches. The company concludes, and we agree, that it does not need to do any more work to meet regulatory objectives. However, the company needs to consider the effect of work it is doing now on the viability of future options, for example to retrieve waste from the vaults or trenches, or to further protect the facility.

LLW Repository Ltd has used the output from the 2011 ESC to refine the LLWR waste acceptance criteria and make sure that disposal practices remain optimal. For example, the company proposes to implement a number of emplacement strategies for significant waste streams, including the exclusion of certain high specific activity waste from within 5 metres of the engineered cap surface. We consider that these proposed emplacement strategies provide an effective and practical way of optimising the placement of the waste.

We expect the optimisation process to continue throughout the design, construction and operation of the repository. We have made a number of recommendations to LLW Repository Ltd on areas for improvement in future, to help make sure that the repository remains optimised throughout the period of authorisation. Work addressing the areas identified for improvement in the engineering forward programme, as summarised in section 3.4.1, will need to demonstrate that solutions are optimised and consistent with the application of best available techniques and assumptions within the 2011 ESC. We have also raised an FI requiring LLW Repository Ltd to assess the significance of discrete items, which are recognisable items that may contain a significant radiological burden, in disposed and stored waste. In addition, we asked LLW Repository Ltd to demonstrate that the disposal of discrete items in waste that is currently stored at the LLWR is consistent with best available techniques.

At the end of our review we concluded that LLW Repository Ltd has presented an optimised design for the stage of development of the facility. However, we note that there is further, more detailed design work to be done before construction. There remains clear scope for further optimisation in a number of areas, for example container design, the protection of containers by refinement of vault capping timing and sequencing and the capping of the trenches. We have already discussed some of these issues in Sections 3.3.2 and 3.4.1. LLW Repository Ltd has started programmes of work to progress these issues and we will review its progress in this area, applying appropriate scrutiny to developing designs. A number of FIs that we raised relate to engineering development and therefore optimisation. We will review progress against these. We also expect future optimisation work to be appropriately documented and substantiated.

3.5. Site understanding

Our review of site understanding demonstrated in the 2011 ESC covered three distinct areas of work:

- the characterisation of the hydrogeology and geological setting of the repository, together with development of conceptual models and the subsequent use of hydrogeological and geological information throughout the ESC
- the environmental monitoring programme used to inform the ESC and to monitor the performance of the repository throughout the period of authorisation
- the characterisation of the erosion of the coast, expected to result in the eventual disruption of the repository

Summaries of our main findings in each of these areas are provided in the following sub-sections.

3.5.1. Site characterisation

LLW Repository Ltd summarises its current understanding of the geological and hydrogeological setting of the LLWR in the Level 2 Hydrogeology report (LLW Repository Ltd 2011h). During our review we had to review information in a number of Level 3 reports, including Michie et al. (2010), Smith (2011), Jackson (2011) and Hartley et al. (2011a, 2011b, 2011c).

The area in and around the LLWR has been extensively investigated, which includes the drilling of approximately 650 site investigation boreholes. The current level of site understanding can, therefore, be considered to be well established. Much of this investigation work was carried out before the 2002 ESCs. Since then, LLW Repository Ltd has carried out further targeted investigations (for example, coastal geophysics investigations and the drilling of new groundwater monitoring wells including off-site locations) and collected information opportunistically (for example, the geological logging of the Vault 9 excavations) to improve its understanding. Given the stage of repository development, we consider this to be appropriate.

During the development of the 2011 ESC, LLW Repository Ltd prepared revised conceptual models of the geology and hydrogeology in an iterative manner, leading to an improved geoscientific understanding of the site. The company used these models to develop groundwater flow models to characterise the flow of groundwater and predict migration of contaminants via groundwater to the coastal region. The company also used these models to project changes in flow over time as a result of degradation of the engineered barrier systems and climate and landscape change.

LLW Repository Ltd updated these models a number of times over a relatively short period, leading to some loss of clarity in the 2011 ESC documentation and inconsistencies between information used in the latest versions of the conceptual models and the groundwater flow models. We made recommendations to LLW Repository Ltd to make sure that it improves the audit trail between site characterisation information and its subsequent use across the ESC.

The heterogeneous nature of the Quaternary deposits underlying and adjacent to the LLWR means that it may not be possible to characterise precisely the layout of low and high permeability lithologies. We consider that the geological interpretation and resultant modelling of the Quaternary geologies is appropriate. But, we note that there will always remain a significant level of uncertainty over the behaviour of groundwater within these geologies at a small scale (10s to 100 metres).

Despite this, we consider that the quality of geological and hydrogeological investigations and their subsequent interpretation is high. LLW Repository Ltd has used site information appropriately to inform its geological and hydrogeological conceptualisation and modelling. The resulting interpretation of the geological and hydrogeological site context has appropriately supported the development the 2011 ESC with appropriate accommodation of the remaining geological uncertainty. We believe that the current level of site understanding is well established and we do not anticipate any significant changes in the understanding of the hydrogeological environment and the resulting site conceptualisation in the near future. We consider that LLW Repository Ltd has appropriately identified and investigated the main uncertainties associated with the geological and hydrological environment and taken account of them in the groundwater flow and assessment models.

There is a plume of tritium contamination in groundwater below and down gradient of the trenches, resulting from past disposals of waste in the trenches. Since emplacement of the interim cap over the trenches and a cut-off wall around the north-eastern and north-western edges of the trenches in the early 1990s, tritium concentrations have significantly decreased and continue to decline. Current concentrations of tritium in this plume are not high enough to affect either the environment or human health receptors, via pathways currently in existence. However, we have raised an FI, which sets out our expectations for LLW Repository Ltd's continued monitoring and characterisation of the tritium plume throughout the period of authorisation. This monitoring will inform an improved understanding of the past release, identify any potential changes to the contamination plume resulting from future site development and assist in the understanding of site hydrogeology and contaminant migration pathways.

We have raised an FI requiring LLW Repository Ltd to produce a comprehensive forward programme for each subject area of the 2011 ESC. This should include specific areas that we have identified need further investigating to update the geological and hydrogeological site characterisation. This includes, for example, further investigation and assessment of the hydrogeological properties of the environment immediately below and next to current and future vaults. This will better inform the site evolution models and understanding of the re-saturation of the vaults. All of these recommendations are designed to improve the understanding of the geosphere and reduce key uncertainties.

3.5.2. Coastal evolution

LLW Repository Ltd summarises its current understanding of the most likely evolution of the coast adjacent to the LLWR leading up to the expected destruction of the repository in the Level 2 Site evolution report (LLW Repository Ltd 2011i). In our review, we also assessed further detail and substantiation of the predicted evolution sequence, which is summarised by Fish et al. (2010).

In the 2002 ESCs, coastal erosion was only one of three main potential destruction scenarios assessed for the LLWR, the other two relating to glaciation scenarios. However, climate change science has significantly moved on since then. The latest studies indicate that there is likely to be a prolonged period of global warming and sea level rise, which is projected to last for tens of thousands of years. Projections show that glaciation at the latitude of the LLWR is unlikely to happen within the next 100,000 years. Regardless of this conclusion, we asked LLW Repository Ltd to consider alternative scenarios where coastal erosion is significantly delayed or does not happen. Its assessment concluded that the only credible scenarios under which the LLWR may escape coastal erosion are those where the sea level does not rise significantly and begins to fall within a few thousand years. LLW Repository Ltd's predictions show this scenario is very unlikely to happen. We conclude that the probability of the LLWR not being eroded over a very long time is very low, but cannot be ruled out.

LLW Repository Ltd has used output from recent climate change studies, combined with extensive characterisation and modelling of the Drigg coastline, to project that the LLWR is likely to start to be destroyed by coastal erosion in a period of a few hundred to a few thousand years from now. Our review of this work has focused on:

- the use of climate change science in developing and conceptualising the erosion sequence
- understanding the response of the Drigg coastline to sea level rise
- the interaction of the eroding coastline with the repository
- the development of coastal evolution scenarios to use in exposure assessments
- identifying and dealing with uncertainty

We consider that LLW Repository Ltd has carried out a comprehensive investigation and assessment of how the facility could potentially evolve, focusing on the timing, nature and consequence of coastal erosion and the resulting expected disruption to the site. The investigation has used appropriate local information together with up-to-date international climate forecasts and coastal process science to identify the nature and timing of disruption to the site.

LLW Repository Ltd has identified realistic factors expected to control the timing and nature of disruption to the site by erosion and considered a credible range of potential erosion scenarios. The company has used the outputs of the site evolution studies to conclude that repository disruption will most likely happen due to cliff recession, rather than site flooding and inundation. This is because cliff recession is projected to lead to initial disruption of the facility before the sea level rises sufficiently to cause flooding and inundation. The company concludes the most likely direction of erosion is from the coast, rather than disruption through estuary development or lagoon formation. However, because of the complexity of the repository setting, there is a great deal of uncertainty over the form and direction of disruption resulting from coastal erosion. LLW Repository Ltd has appropriately taken account of this uncertainty by identifying all reasonable ways the site might be disrupted. Erosion of the LLWR will be delayed if there are no further sea level rises, but is still projected to happen over an extended timeframe of between 2,500 and 5,000 years after present. Therefore, LLW Repository Ltd considers that there is a low probability that the

LLWR will remain intact for more than 2,500 years. We agree that these projections are reasonable and represent best available knowledge at this time.

We recognise that the level and significance of uncertainty associated with the timing and nature of disruption to the site is high given its reliance on externally derived climate change information and the need to characterise the response of a complex coastal environment to the external changes. This means that understanding of the timing and conceptualisation of coastal erosion may change throughout the period of authorisation as understanding develops and uncertainties are reduced.

We are satisfied that LLW Repository Ltd has adequately taken account of, recognised and bounded these significant uncertainties within its assessments. To make sure that the predictions of the beginning of repository erosion are appropriately constrained, the 2011 ESC has presented an erosion scenario corresponding to the more extreme upper end estimates of high sea level change rates. We are, therefore, satisfied with LLW Repository Ltd's assessment that the projected earliest time for coastal erosion to begin at the site is not likely to reduce as the projections are refined in the future.

We consider that LLW Repository Ltd has provided a credible assessment of the evolution of the Drigg coastline, which results in the predicted disruption of the LLWR by coastal erosion. The resulting narrative and conceptualisation has provided an important input to many safety arguments made throughout the 2011 ESC and informed the safety assessment calculations. LLW Repository Ltd predicts coastal erosion of the LLWR will begin between several hundred and several thousand years from now. We are satisfied that this assessment is realistic and adequately takes account of uncertainties.

As part of the optimisation process, LLW Repository Ltd has considered the viability of coastal defences in preventing disruption to the site. The nature of coastal erosion, uncertainties in direction and the long timescales predicted before erosion begins mean that these defences may not be viable, but options for their construction are not foreclosed by anything being done today. In the future, the operator, the Environment Agency or others with responsibility for the LLWR may consider sea defences necessary. But, we agree that these defences would be best designed and built closer to the time when they may be required.

We require LLW Repository Ltd to maintain an ongoing forward programme of coastal monitoring and to keep up-to-date with the latest research on long-term climate change. We raised one FI and made a number of recommendations to make sure that LLW Repository Ltd continues to understand more about how the site might evolve. Given the current level of uncertainty in the projections of climate change and coastal evolution, it is likely that understanding of the coastal erosion sequence will evolve, with an associated reduction in uncertainty. However, on the basis of current scientific evidence, we agree with LLW Repository Ltd that the most likely result of coastal erosion will be that the LLWR will eventually be completely destroyed by the eroding coastline.

3.5.3. Monitoring

LLW Repository Ltd summarises its current monitoring programme in the Level 2 Monitoring report (LLW Repository Ltd 2011j). The company also submits annual monitoring reports to the Environment Agency in response to Schedule 9 Requirements 7 and 8 of the environmental permit. These requirements cover monitoring of the interim trench cap and cut-off wall and monitoring of groundwater contamination around the LLWR. LLW Repository Ltd provides appropriate monitoring information to demonstrate compliance with statutory discharge limits as outlined in the site's environmental permit. We also reviewed a number of Level 3 documents, including the long-term monitoring strategy (Hayes et al. 2011) and a subsequent review of the monitoring programme (LLW Repository Ltd 2012b).

LLW Repository Ltd has developed and implemented an extensive and high quality environmental monitoring programme that is capable of supporting the 2011 ESC and providing environmental understanding throughout the period of authorisation. This includes comprehensive quality systems and procedures, which have given us much confidence in the quality and appropriateness of the monitoring information used to support the 2011 ESC.

We are satisfied with LLW Repository Ltd's monitoring capability for important environmental pathways. However, we have identified the need for more focussed monitoring of the leachate and

gas management systems to provide reassurance that the system is performing as projected. These requirements are included in FIs.

We consider that LLW Repository Ltd has appropriately used a wide range of environmental monitoring information to inform the conceptualisation and assessment of the LLWR. However, as the LLWR develops, the company should place a greater emphasis on collecting and using environmental monitoring data from the site rather than using literature data to inform and develop the 2011 ESC.

Future monitoring at the LLWR will play an important role in increasing understanding and reducing uncertainties in the ESC. LLW Repository Ltd recognises it needs to continue to update and review its environmental monitoring programme throughout the period of authorisation and especially during the development of new vaults, capping or the cut-off-wall. However, we do not consider that the 2011 ESC adequately sets out how ongoing monitoring can be used, in some instances, to reduce relevant significant uncertainties.

We require LLW Repository Ltd to develop a forward monitoring strategy for the lifetime of the site that is appropriate to support the ESC, demonstrates compliance with the permit, as well as reducing significant uncertainties. This strategy should be clearly set out in future versions of the ESC. It should take into account the 2011 ESC and our review, supporting assessments (for example, the Habitats Regulations Assessment) and any wider learning and ongoing data collection. These requirements are set out in an FI.

We will continue to work with LLW Repository Ltd to make sure that environmental monitoring provision continues to support the ESC. We have put forward a number of recommendations and FIs that the company needs to address so that it continues to meet our requirements in the future.

3.6. Assessment

LLW Repository Ltd assessed the performance and safety of the LLWR during the period of authorisation[5] and the post-closure period. It looked at the impacts to human health, the environment and non-human biota (that is, plants and animals) from both the radioactive and non-radioactive parts of the inventory. LLW Repository Ltd assessed future impacts, taking into account the anticipated development of the site, as outlined in the site development plan, and, over the longer-term, the projected impacts of climate and landscape change and future human actions.

The overall quality of the 2011 ESC technical assessment submissions is of a high standard. The structure of the ESC is coherent and its arguments are generally clear, with good referencing of associated and supporting reports. The 2011 ESC assessment is documented in 4 Level 2 reports, which cover environmental safety during the period of authorisation, long-term radiological impacts, non-radiological impacts and impacts to non-human biota (LLW Repository Ltd 2011k, 2011l, 2011m, 2011n). We also needed to review a large number of Level 3 reports (including Hicks and Baldwin 2011; Kelly et al. 2011; Limer and Thorne 2011; Limer et al. 2011; Thorne and Schneider 2011; and Towler et al. 2011) and output from several programmes of work LLW Repository Ltd carried out after it submitted the 2011 ESC, either as a direct result of queries raised by us or arising from LLW Repository Ltd's ongoing work programme (for example, Kelly and Berry 2013; Sumerling 2013a, 2013b, 2013c).

LLW Repository Ltd has carried out separate assessments for the period of authorisation and post-closure periods. We queried this with respect to the groundwater pathway, as the two assessments used different assumptions relating to site engineering and covered an overlapping time period. We consider that the presentation of discharges and impacts from the assessments for the period of authorisation and for the subsequent period as a single output would help LLW Repository Ltd communicate the nature and significance of environmental impacts. We have made this recommendation to LLW Repository Ltd.

[5] Operational safety at the LLWR is regulated by the Office for Nuclear Regulation and is outside the scope of the ESC.

Projected discharges from the trenches into groundwater presented in the 2011 ESC were affected by the observed poorer performance of the interim trench cap than assumed (see section 3.4.1). Subsequently, LLW Repository Ltd presented updated calculations and we found these to be acceptable.

Assessed doses during the period of authorisation are below the legal constraints on radiation doses to members of the public set out in EPR10 and the GRA dose guidance levels (0.3 mSv annual dose from any source from which radioactive discharges are made, 0.5 mSv annual dose from the discharges from any single site and 20 μSv annual dose for discharges via the groundwater pathway) except in one case. We discuss this below.

After submitting the 2011 ESC, LLW Repository Ltd informed us of an error it had found in the assessments of direct radiation and dust inhalation dose rates for the period of authorisation. The error related to radionuclide inventories assumed for the future, taking into account radioactive decay. This meant that doses had been underestimated in the 2011 ESC. LLW Repository Ltd provided updated calculations (Penfold 2013a, 2013b). The most significant increase was to doses from direct radiation (peak annual doses of 600 μSv for a theoretical person living outside the site boundary adjacent to Vault 13). This is an approximately four-fold increase over the earlier doses, which results in assessed total annual doses in excess of the source related dose constraint of 300 μSv y^{-1}.

LLW Repository Ltd claims that these revised doses are overestimates of annual direct radiation because existing houses are located some distance from the site boundary and houses would not be developed on this land as it is designated as a Site of Special Scientific Interest. It, therefore, concludes that these doses would not happen. Given that the LLWR is a nuclear licensed site, the Office for Nuclear Regulation would also need to be satisfied that direct radiation doses during future site operations are kept as low as reasonably practicable. We agree that the pessimisms used in the revised assessment mean that the dose constraint is unlikely to be exceeded in practice. In future, direct radiation exposures will be monitored and managed by an appropriate waste emplacement strategy. Action would be taken in response to any unacceptable measured dose rates. LLW Repository Ltd has to continue to carry out regular dose rate monitoring and reporting in accordance with requirements of its environmental permit.

Work that LLW Repository Ltd carried out after it submitted the 2011 ESC, to correct identified errors, to address queries from our review and as part of the ongoing ESC team work programme, has meant the C-14 gas and groundwater pathway assessment calculation results presented in the 2011 submission are now obsolete. The audit trail for these updates was included in the Developments report (LLW Repository 2013a), but we had to ask LLW Repository Ltd to clarify the latest calculation cases and dose and risk results that it is using to support its permit application, as these were not included. The company has since provided a satisfactory explanation (Cummings 2013).

Currently, there are no wells used for abstracting drinking water in the area between the LLWR and the coast, where any contamination from the LLWR is predicted to occur in groundwater. We consider it unlikely that a well will be drilled before the end of the period of authorisation. In any event, LLW Repository Ltd has assessed the annual dose from drinking groundwater from a hypothetical well intercepting the modelled contamination plume from the LLWR to peak at 3 μSv, which would be received at the present day.

For the post-closure assessment, LLW Repository Ltd assessed a 'reference case', which was based on best estimate assumptions about the future inventory, evolution of the facility and coastal erosion. The company also assessed a wide variety of 'variant cases', using alternative assumptions to investigate uncertainty in both evolution scenarios and significant parameters. We consider this approach is consistent with the GRA and that LLW Repository Ltd has assessed a reasonable range of alternative scenarios and potentially exposed groups that encompass all reasonable futures.

The main impacts to human exposed groups during the post-closure period are dominated by the groundwater well pathway. LLW Repository Ltd updated the groundwater pathway calculations after submitting the 2011 ESC to take into account the effect of complexants on contaminant migration and to correct minor errors in decay chains (Kelly and Berry 2013). For the reference

disposal area, LLW Repository Ltd initially assesses a peak risk of about 4 x 10^{-8} y^{-1} occurring at about 2250 AD (that is 2 orders of magnitude below the risk guidance level and about 170 years after completion of the final cap); the dominant radionuclide is C 14. For the extended disposal area the peak risk is projected to be an order of magnitude higher at 2 x 10^{-7} y^{-1}, again dominated by C-14.

As noted in section 3.3.2, the 2011 C-14 gas pathway assessment was based on an overly conservative model, which projected that the risk guidance level would be exceeded after the end of the period of authorisation. In September 2013, LLW Repository Ltd presented a revised and better underpinned assessment of radiological impacts from C-14 bearing gases. Annual risks are now assessed to be about 1.8 x 10^{-7} to a person representative of the group at greatest risk (a smallholder living on the final cap). We have reviewed this additional assessment and are satisfied that it is more realistic and appropriate than the original assessment. We support LLW Repository Ltd's programme of longer term work in this area. This includes: maintaining an up-to-date scientific understanding of relevant processes and the characteristics of future C-14 bearing waste; further experimental and modelling work; and maintaining an awareness of national and international initiatives to improve understanding of the partitioning of C-14 into plants.

LLW Repository Ltd provided the results of illustrative, ‘what if’ assessments to project potential doses associated with exposure to waste during and after exposure of the waste by an eroding coastline. The company compared these doses to an annual dose of 20 µSv (which is equivalent to the risk guidance level, assuming exposure is certain to happen). We agree that this approach is appropriate given the uncertainties. All results for the reference case were below 20 µSv y^{-1}.

In the 2011 ESC, LLW Repository Ltd noted that it had not assessed the radiation doses that people exploring the beach and foreshore might be exposed to by possible encounters with small radioactive particles or discrete items of waste with a significant radioactive burden following erosion of the LLWR. We questioned this omission and asked the company to address it. This led to a range of additional 'what if' assessments regarding possible doses to different age groups (Sumerling 2013b, c). LLW Repository Ltd identified 3 types of particles that could reasonably be expected to be received for disposal at the LLWR, albeit in small amounts, that have the potential to lead to a committed effective dose in the range of 3 to 20 mSv. These were radium paint (manufactured to Admiralty specification), the highest alpha-rich Sellafield beach particle found to date and pressurised water reactor (PWR) spent fuel particles (Sumerling 2013c). In no case were annual dose levels projected to be higher than 20 mSv.

Our GRA assessment criteria for scenarios occurring after closure of the LLWR are generally defined in terms of 'annual risk' to an individual. On this risk basis, we believe the risks of harm from encountering these particles are acceptable (that is, the risks are less than 1 x 10^{-6} y^{-1}). We have produced supplementary guidance to Environment Agency assessors on the disposal of discrete items and particles to the LLWR (Smith 2014). This guidance includes a ‘test of significance’ that should apply to potential exposure to these items as a result of casual curiosity or deliberate searches. This new test of significance considers the effective dose to any person during and after coastal erosion of the LLWR and should not exceed a dose guidance level in the range of around 3 mSv y^{-1} to around 20 mSv y^{-1} (consistent with the existing guidance for human intrusion under Requirement R7 of the GRA). We consider that the projected doses associated with exposure to particles and discrete items from the LLWR during coastal erosion are consistent with this test of significance.

LLW Repository Ltd has recently implemented further controls in the WAC to cover the situation where a significant assessed effective dose could arise from the ingestion of particles that carry a significant burden of radioactivity. These controls seek to limit, as far as reasonably practicable the disposal of these particles and waste that could give rise to these particles (LLW Repository Ltd 2014). The revised WAC also include new controls on discrete items, which are based on a dose rate guidance value of 20 µSv h^{-1} as a standard for future limits on the disposal of these items.

LLW Repository Ltd has provided a deterministic assessment including a qualitative evaluation of human intrusion events before and during the coastal erosion period. LLW Repository Ltd calculated doses to persons associated with a range of potential intrusion scenarios that it considered representative. These doses were compared with our dose guidance range of 3 - 20

mSv y^{-1}. All the intrusion events the company has assessed are consistent with these dose guidance values and, consequently, no event has been identified that could give rise to 'severe deterministic injury'. We agree with this conclusion.

Overall, we judge that LLW Repository Ltd has demonstrated that assessed radiological doses and risks for the periods before and after closure of the LLWR all fall within relevant guidance levels. The company's radiological capacity assessments are consistent with the dose and risk assessments in the 2011 ESC. However, LLW Repository Ltd needs to consider how the LLWR inventory will be managed in future in relation to the assessed capacity, when assessments may change as a result of new information. We also require LLW Repository Ltd to explore further the relationship between disposed inventory and dose/risk, in particular with respect to the inventory management of C-14 and using output from probabilistic calculations, where appropriate, to determine radiological capacity. We have issued two FIs regarding these issues.

LLW Repository Ltd assessed the present day effects on non-human biota from the LLWR to be at levels below regulatory concern and that the effects are unlikely to increase significantly during the period of authorisation. We agree with this conclusion. After closure of the LLWR, dose rates to some organisms may exceed a 10 µGy h^{-1} screening level. In particular, during the onset of early coastal erosion, plants and invertebrates inhabiting the storm beach could receive dose rates slightly in excess of 100 µGy h^{-1}. However, we have reviewed the evidence LLW Repository Ltd submitted regarding the relative radio-insensitivity of these species and we have concluded that these doses will cause no perceptible harm. We have made a number of recommendations to LLW Repository Ltd on areas for future improvement of the non-human biota assessment, so that it continues to meet our requirements. This includes considering the adjacent Drigg Coast Special Area of Conservation and Site of Special Scientific Interest as a specific receptor.

As discussed in section 3.3.1, the non-radioactive part of the LLWR inventory is highly uncertain as non-radioactive contaminants in waste streams have not been well characterised in the past. LLW Repository Ltd has addressed this uncertainty by using conservative assumptions in the assessment source term, both in terms of selecting worst-case (this is, most toxic) reference organic substances and assumptions on the availability of substances for leaching. We consider that output from the non-radioactive contaminant assessment model is conservative.

For the period of authorisation, the results of the non-radioactive contaminant assessment indicate that concentrations of all inorganic substances are expected to remain below the relevant assessment standards in the groundwater underlying the LLWR throughout the assessment time. Measurable concentrations of the hazardous substances benzene and vinyl chloride are projected to have occurred in the past in groundwater underlying some of the trenches. Due to degradation, present day concentrations of both substances in groundwater underlying the trenches are assessed to be negligible. Assessed discharges of hazardous substances and non-hazardous pollutants from the LLWR vaults are zero due to the dilute nature of the leachate and the effectiveness of the capping and the leachate management systems.

At the end of the period of authorisation, concentrations of organic hazardous substances in groundwater underlying the site will be zero or close to zero due to biodegradation. However, LLW Repository Ltd projects that concentrations of chromium[6], plus a number of non-hazardous pollutants including lead, nickel, molybdenum and zinc, will exceed the LLWR's assessment standards in groundwater underlying the LLWR several hundred years after the end of the period of authorisation.

The majority of the identified non-radioactive groundwater discharges are likely to be associated with the long-term corrosion of metals in the waste and the metal container used for disposals. Preventing and limiting these discharges is technically very difficult to achieve because of the need for a design approach that is optimised to minimise radiological impacts, as required by legislation

[6] Chromium may be present in a number of oxidation states (valences). In its hexavalent state, chromium has been given an interim status of a hazardous substance by the Joint Agencies Groundwater Directive Advisory Group; no valency data are available to determine the proportion of chromium likely to be in this form within disposed waste at the LLWR.

and the GRA. Given the conservative nature of the assessment model source term and associated uncertainties, we consider that any impacts in the long term are likely to be localised and will not contravene the requirements of the Groundwater Directive or result in a net environmental dis-benefit. We consider that the proposals are optimised regarding radiological impacts and that this optimisation process has appropriately taken account of non-radiological impacts and their projected timing.

LLW Repository Ltd's non-radiological contaminant assessment for the groundwater pathway was carried out in a similar way to the radiological assessment for the groundwater pathway. We consider that this approach was suitable and sufficient to meet the requirements of the GRA. However, we have identified scope for improvement, for example, selecting assessment criteria and compliance points that are equivalent to those in our guidance on hydrogeological risk assessment for a conventional landfill (Environment Agency 2011). Given the considerable uncertainty in this assessment, we have made several recommendations and raised a FI covering areas for improvement that we wish to see addressed in an updated hydrogeological risk assessment. These improvements should also inform the next update of the ESC.

In summary, we consider that, in the 2011 ESC, LLW Repository Ltd demonstrates an understanding of the effects on human health and the wider environment, during the period of authorisation and subsequently, from the radioactive and non-radioactive components of past and future disposals to the LLWR. LLW Repository Ltd has used the available information to demonstrate that an appropriate standard of environmental safety is achieved at the LLWR now and will continue to be at all times in the future. However, as outlined above, we have identified several areas for future improvement, which we expect LLW Repository Ltd to demonstrate progress against.

3.7. General observations

In our review we have made a number of observations that apply to all the review group areas and relate to the whole 2011 ESC. We summarise these general observations in this section.

As noted elsewhere in this document, we consider the overall quality of the 2011 ESC technical submission to be high. LLW Repository Ltd set out its approach to developing the 2011 ESC early on in the process (Baker et al. 2008). This reassured us that its programme of work could meet our regulatory requirements. Monthly liaison meetings with the ESC Project Team gave us further confidence in the way its work was progressing. It also allowed us to share understanding and gave us the opportunity to clearly describe what we expected the developing ESC to achieve. We welcome the continuation of regular liaison meetings.

We consider it positive that the 2011 ESC generally focused on 'important' issues, an improvement over the 2002 ESCs and we continue to expect this focus. For example, we support the focus on shorter timescales given the expectation now of coastal erosion within a few hundred to a few thousand years. However, areas of focus should continue to be reviewed and other scenarios not ignored, such as delayed coastal evolution, which must be considered proportionately.

We carried out several audits of LLW Repository Ltd's quality assurance and management arrangement procedures during the course of our review. These audits provided evidence that underpins our view that the 2011 ESC was prepared using appropriate systems of control and to a high standard. We found evidence of good practice during our audits, for example further checks made by a contractor organisation identified that it had been supplied with the wrong input files for one of its models.

LLW Repository Ltd identified several errors in the models supporting the 2011 ESC after it had submitted the 2011 ESC to us, as discussed in section 3.6. The company communicated these errors to us and it acted swiftly to update the calculations and assess the implications. The errors were not significant enough to affect the overall conclusions of the 2011 ESC.

LLW Repository Ltd used elicitation exercises to understand how specific parts of the disposal system will evolve over time. For example, the degradation of engineered barriers and the biogeochemical evolution of the waste. We support the use of this approach but would expect the company to make increased use of site, experimental and material-specific performance data

during the development of the detailed engineering design. Similarly, throughout the 2011 ESC, we found LLW Repository Ltd has tended to rely on models to make the case as opposed to using site or analogue data. We expect the use of model output and elicitation exercises to be proportionate and recommend that in future ESCs the company combines this with experimental or site data where possible.

As discussed further in section 5, the forward work plan submitted by LLW Repository Ltd was documented at a high level. We have raised an FI to request that the company develops a more detailed plan to support the 2011 ESC.

Apart from several studies that provided evidence on past disposal practices and the locations of significant disposals in the trenches and, at a high level, the human intrusion and coastal erosion assessments, LLW Repository Ltd did not address the effects of particles and discrete items in the 2011 ESC as submitted in May 2011. After it had made its submission, the company looked at the effects of particles and discrete items on impacts via the coastal erosion and human intrusion pathways and has implemented new WAC to provide future controls on these items. In a future submission, we would expect the issue of heterogeneity to be more fully integrated into the ESC, taking into account learning and development from the 2011 ESC and with impacts assessed for all relevant pathways.

LLW Repository Ltd has made several changes to the LLWR WAC to take into account the 2011 ESC. The company plans further changes subject to it receiving a revised permit. We note that the WAC are quite correctly driven by safety and transport issues as well as by the ESC. LLW Repository Ltd should make sure that there is clear ownership of the WAC and that the ESC Project Team input to all changes to ensure continued consistency with the ESC. The company should support waste consigners to make sure that changes are effectively implemented.

It will be important for LLW Repository Ltd to maintain relevant skills in the ESC Project Team throughout the period of authorisation. We have made several recommendations to this effect. We welcome the fact that LLW Repository Ltd identifies that ESC technical specialists are part of the succession plan for the ESC and will, therefore, be available to continue to develop and apply the ESC as a site management tool into the future. Engineering and operations staff at the LLWR need to work closely with the ESC Project Team to make sure that any changes in site engineering and practice are consistent with the ESC.

As the LLWR develops, LLW Repository Ltd will need to refocus its efforts away from ESC development towards practical implementation of it on site (for example, construction), the ongoing optimisation of the engineering design, support to disposal operations and decisions (for example, waste acceptance) and ongoing ESC maintenance. We support the fact that LLW Repository Ltd has addressed how the ESC Project Team will support these areas of work and will use its experience to support site operations, while maintaining awareness of the ESC and developing skills and experience associated with it.

3.8. Comparison with the 2002 ESCs

In our earlier review of the 2002 ESCs, we concluded that, although we considered that the site operator (then BNFL) provided a broad indication of the impact of the repository, it failed to 'make an adequate or robust argument for continued disposals of LLW because:

- Estimates of doses and risks from existing disposals to members of the public in the future significantly exceeded current regulatory targets.
- BNFL indicated that the LLWR was likely to be destroyed by coastal erosion in 500 to 5,000 years.
- The 2002 safety cases did not sufficiently consider optimisation and risk management to demonstrate that impacts will be as low as reasonably achievable' (Environment Agency 2005a).

LLW Repository Ltd provided evidence in the 2011 ESC that understanding of the site has significantly improved since 2002. Taking this evidence into account, we consider that our main concerns with the 2002 ESCs have been either addressed in the 2011 ESC or have been superseded. In particular:

- The understanding that the LLWR is almost certain to start to be destroyed by coastal erosion within a few hundred to a few thousand years. Therefore, the 2011 ESC focuses on a much shorter timeframe than the 2002 PCSC. The 2002 PCSC assessed scenarios involving climate cooling and subsequent glacial erosion of the site. Impacts significantly higher than the risk guidance level were projected tens of thousands of years in the future. This situation is now not thought likely to happen.
- Significant effort has been made to understand past disposals; in particular disposals to the trenches in terms of activity, waste form, heterogeneity and location of significant disposals. This has led to better understanding of significant disposals.
- As a result of the increased focus on the assessment of coastal erosion, combined with improvements to the inventory, assessment and site understanding, LLW Repository Ltd has been able to show that doses and risks are now below the guidance levels. We consider that LLW Repository Ltd has made a reasonable range of cautious assumptions about future scenarios and human habits and behaviour in the 2011 ESC. We have no reason to believe that the company's assessments have underestimated potential doses.
- The engineering design of the facility, including future vaults and, in particular, the closure engineering system has been subject to extensive optimisation, resulting in updated designs. We consider that the site development plan has been appropriately optimised for the current state of development of the LLWR.

In our review of the 2011 ESC, we have assessed whether all our queries on the 2002 ESCs, as recorded in the IAFs, have been addressed. We have concluded that the vast majority of these issues can be closed, either because they have been adequately addressed through work carried out since 2002 or because they are no longer relevant (Environment Agency 2015h). A small number of issues are being taken forward as recommendations (as documented in the review group reports; Environment Agency 2015b, 2015c, 2015d and 2015e) or in FIs (Environment Agency 2015f). We do not consider any of these outstanding issues to represent a significant shortfall against regulatory requirements. We believe that they can reasonably be addressed through LLW Repository Ltd’s future and ongoing improvements to its understanding of the site and ESC.

4. Meeting the requirements of the GRA

4.1. Introduction

The GRA (Environment Agency et al. 2009) sets out the framework within which we regulate near-surface disposal facilities and our intended regulatory approach. The fundamental protection objective of the guidance is to make sure that all disposals of solid radioactive waste to facilities on land are made in a way that protects the health and interests of people and the integrity of the environment, at the time of disposal and in the future, inspires public confidence and takes account of costs.

The guidance focuses on 5 principles for solid radioactive waste disposal. These are as follows:

- **Principle 1. Level of protection against radiological hazards at the time of disposal and in the future.** Solid radioactive waste shall be disposed of in such a way that the level of protection provided to people and the environment against the radiological hazards of the waste both at the time of disposal and in the future is consistent with the national standard at the time of disposal.
- **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.
- **Principle 3. Level of protection against non-radiological hazards at the time of disposal and in the future.** 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 wastes that present a non-radiological but not a radiological hazard.
- **Principle 4. Reliance on human action.** Solid radioactive waste shall be disposed of in such a way that unreasonable reliance on human action to protect the public and the environment against radiological and any non-radiological hazards is avoided both at the time of disposal and in the future.
- **Principle 5. Openness and inclusivity.** For any disposal of solid radioactive waste, the relevant environment agency shall establish ways of informing interested parties and the public about regulatory goals, processes and issues and consult in an open and inclusive way.

Supporting these principles are 14 more specific requirements, which, if fulfilled proportionately to the hazard presented by the waste, should make sure that the principles are properly applied.

LLW Repository Ltd provides a summary of how it has addressed the requirements in the GRA in the 2011 ESC (LLW Repository Ltd 2011a). We believe this demonstrates that the company has met them appropriately, when supported by the evidence presented in response to further information requests from us. We provide our assessment of the extent to which the 2011 ESC has met each of the requirements of the GRA in the following sections.

4.2. Requirement R1: Process by agreement

The GRA states that:

'The developer should follow a process by agreement for developing a disposal facility for solid radioactive waste.'

The LLWR is not a new facility and so a process by agreement is not required. However, we consider that elements of the process and expectations detailed within the GRA are still relevant.

We welcome the fact that LLW Repository Ltd has taken the guidance into account in formulating their engagement with us and others.

We are satisfied that LLW Repository Ltd has engaged effectively with us throughout the development and review of the 2011 ESC. This has allowed agreements to be established on information provision, timescales and requirements. Monthly ESC liaison meetings with us were a major factor in achieving this, with regular meetings continuing after the 2011 ESC had been submitted.

LLW Repository Ltd made good use of a number of documents, such as its ESC approach document (Baker et al. 2008), to define how it would produce and implement the 2011 ESC. The future development of the ESC has also been adequately recognised, for example within forward programmes of work (LLW Repository Ltd 2011o), an implementation plan (LLW Repository Ltd 2012a) and relevant procedures (LLW Repository Ltd 2013b). We welcome the fact that LLW Repository Ltd recognises the ESC is a 'living' case that is vital to managing the LLWR. Ongoing engagement between LLW Repository Ltd and us will be essential in making sure that we continue to agree on the development and application of the ESC during routine operations and site development.

LLW Repository Ltd has proposed annual, periodic (approximately every three years) and major (approximately every 10 years) reviews of the ESC, with the exact timing of major reviews to be agreed with us (LLW Repository Ltd 2013a). We agree these proposals are appropriate and will require reviews as we consider necessary through any environmental permit. As well as the planned ESC reviews, the ESC may need to be reviewed if there are significant changes to the site development plan.

In summary, we consider that LLW Repository Ltd has complied consistently with the expectations detailed within Requirement R1 of the GRA. To guide continued improvement of the ESC and to make sure that the ESC continues to meet the requirements of the GRA, we have raised two recommendations associated with Requirement 1 (Environment Agency 2015a).

4.3. Requirement R2: Dialogue with local communities and others

The GRA states that:

'The developer should engage in dialogue with the planning authority, local community, other interested parties and the general public on its developing environmental safety case.'

LLW Repository Ltd has provided evidence of significant engagement at a number of levels with organisations such as the NDA, UK Nuclear Waste Management Ltd, the planning authority, regulators, local communities, customers and a range of other local, national and international organisations such as NuLeaf[7], the NDA National Stakeholder Group, government and international technical bodies (LLW Repository Ltd 2011c). We are generally satisfied that LLW Repository Ltd has adequately recognised and identified relevant stakeholders for engagement, along with relevant mechanisms and the scope of engagement. However, we did ask the company to explain its approach to defining stakeholders through an IRF and were satisfied with its response.

Through the 2011 ESC and supporting documents, LLW Repository Ltd demonstrated that, generally, its engagement on the ESC was suitably flexible, early, ongoing, open and inclusive and that it encouraged 'challenge'. Our input to this process was adequately facilitated. We encouraged LLW Repository Ltd to liaise with other national stakeholders and non-governmental organisations which led to enhancements to engagement programmes.

Overall, we welcome LLW Repository Ltd's commitment to dialogue and the priority it has given to this area of work. We consider that the company liaises adequately with stakeholders, in line with

[7] NuLeaf is the Nuclear Legacy Advisory Forum, a special interest group of the Local Government Association.

expectations detailed within Requirement R2 of the GRA. To guide continued improvement of the ESC and to make sure that the ESC and its development continues to meet the requirements of the GRA, we have raised two recommendations associated with Requirement R2 (Environment Agency 2015a).

4.4. Requirement R3: Environmental safety case

The GRA states that:

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

An ESC is defined as 'a set of claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence. It should demonstrate that the health of members of the public and the integrity of the environment are adequately protected' (GRA paragraph 6.22). The GRA details expectations that a clear ESC is made and provides guidance on the content (section 7 of the GRA).

There are a number of aspects that we consider are particularly important in preparing an ESC and we have focussed on these during our review of the 2011 ESC:

- The ESC should demonstrate a clear understanding of the disposal system in its geological setting as it evolves.
- The disposal system consists of multiple components or barriers; the ESC should include an explanation of, and substantiation for, the environmental safety functions provided by each part of the system.
- When environmental safety needs to be assured over very long timescales, quantitative risk assessments are unlikely to be enough to establish the ESC. We expect the ESC to use multiple lines of reasoning based on a variety of evidence, leading to complementary safety arguments.
- Whilst uncertainties are not in themselves obstacles to establishing the ESC, we expect the ESC to explicitly take them into account and consider where they may be reduced or their effects lessened or compensated for.
- We expect modelling studies to be an important part of the quantitative environmental safety assessment being used to help understand the characteristics and behaviour of the overall disposal system and its component parts.
- Expert judgement is essential in gathering and interpreting evidence and applying it to develop the ESC and use it in the supporting qualitative and quantitative models. In situations where expert judgement is needed to complement or develop arguments or to compensate for data gaps, we would expect appropriate elicitation procedures to be used.

We consider that the presentation and structure of the 2011 ESC, as described in section 1.4, is logical and generally well laid out. We did find some shortfalls such as discrepancies, unclear audit trails and the need to trace evidence back into documents not included in the 2011 ESC submission. However, overall the 2011 ESC was sufficient and comprehensive enough to complete our review, subject to LLW Repository Ltd providing further information in a number of areas, as requested through IRFs (Environment Agency 2015f). We anticipate that lessons can be learned for the next major ESC update from the development of the 2011 ESC, its implementation and feedback on it.

We examined the approach LLW Repository Ltd took to developing the 2011 ESC. In 2008 an approach was documented, which we found suitable and consistent with the requirements of the GRA (Baker et al. 2008). However, we recommend that future versions of the ESC aim to place a greater emphasis on the use of qualitative arguments and alternative lines of reasoning wherever practicable and beneficial to do so, for example use of analogue and experimental data to substantiate performance.

We consider that the 2011 ESC provides a suitable description of the main aspects that may affect environmental safety, including the geology, hydrogeology and hydrology (LLW Repository Ltd 2011h), coastal evolution (LLW Repository Ltd 2011i), the characteristics of the waste (LLW

Repository Ltd 2011d), the design of the facility (LLW Repository Ltd 2011g) and the techniques used to construct, operate and close it (LLW Repository Ltd 2011f). We note that there are still uncertainties and we have raised a number of FIs and recommendations on areas where we require LLW Repository Ltd to carry out further work. In particular, this includes, but is not limited to, continued monitoring of coastal change, keeping a watching brief on climate change predictions, further substantiation of the predicted performance of the engineered barriers and improved characterisation of the non-radioactive component of the disposed and forward inventory. We require LLW Repository Ltd to make sure that its forward monitoring plan aims to reduce significant uncertainties in the ESC where practicable.

The 2011 ESC uses conceptual and mathematical models (implemented via computer codes) to assess the performance of the repository. These show how radionuclides (and non-radioactive contaminants) might be expected to move from the waste through the immediate physical and chemical environment of the disposal facility and through the surrounding geological formations into and through the wider environment. LLW Repository Ltd used detailed system models to investigate the performance of specific parts of the disposal system (for example, groundwater flow and the biogeochemical evolution of the disposal system) and assessment level models to project impacts to human health and the wider environment for the period of authorisation and post-closure period. We note that LLW Repository Ltd aims to make an integrated and consistent evaluation of the environmental performance of the site over the full lifetime of the LLWR. We welcome this integrated approach, but note that there are still some inconsistencies between assessment models for the period of authorisation and post-closure (Environment Agency 2015e).

Through our review and audits of the near field and groundwater models, we are confident that LLW Repository Ltd and its contractors used suitable codes and appropriate quality assurance procedures. However, we recommended that LLW Repository Ltd improves its documentation in this area to help us better understand how the various codes interact, how model output is transferred between different models and how quality assurance procedures are used.

The GRA does not state how an ESC should describe and substantiate the environmental safety functions provided by each part of the system. We found no clear single description of the safety concept for the facility as a whole. However, we were satisfied that the 2011 ESC as a whole does make the case. Without this clear description of the safety concept, we found it difficult to assess the significance that each part of the disposal system makes to the 2011 ESC and determine the implications should one or more function be impaired. In response to our query on this matter, LLW Repository Ltd noted that, although it had not used a formal safety function approach in the ESC, nor analysed the performance of each barrier in turn, it had met the requirements of the GRA as it had:

- developed conceptual models and understanding that cover the performance and evolution of each barrier in detail
- characterised the evolution of the properties of the barriers as a function of time
- understood the role of each barrier in controlling the performance of the overall system (Baker 2013)

Although we agree that the information in the 2011 ESC is sufficient to meet the GRA, we believe that a safety function approach would have explained more clearly the roles and performance requirements of the various components of the disposal system and how they contribute to the overall safety of the facility. We recommend that this approach is used in future updates to the ESC.

Managing uncertainties is a necessary and important part of establishing the ESC. During our review we found a number of shortfalls in LLW Repository Ltd's identification and management of uncertainties, although overall we concluded that the requirements of the GRA had been adequately met for this stage in the operating life of LLWR. The main way of managing

uncertainties is by the use of a 'features events and processes' (FEPs)[8] and uncertainty tracking system (LLW Repository Ltd 2013c), which we believe forms a good basis. To make sure our identified shortfalls are addressed we raised a number of recommendations and an FI. For example, we expect further work to link the forward programme of work to identified uncertainties and development of more systematic processes for identifying uncertainties.

LLW Repository Ltd used expert judgement to elicit data that it used in its assessment of the long-term performance of the facility, in particular relating to the performance of the engineered barriers. We consider that LLW Repository Ltd's use of a formal elicitation process using a group of subject matter experts in a workshop is a suitable way to elicit such data. However, we made a number of recommendations and raised an FI, which seeks improvements to and development of, the elicitation process and its documentation. We also expect to see a move away from elicited to empirical data (site and, where appropriate, experimental data) wherever possible and beneficial to do so.

We expect LLW Repository Ltd to continue to develop its ESC as a live case, with ongoing annual, periodic and major reviews. We expect a forward programme of work to be developed and maintained. A high-level forward programme of work was presented in the 2011 ESC and further detail provided following an IRF seeking this information (LLW Repository Ltd 2011o). Related to this, LLW Repository Ltd also prepared a forward engineering programme to address necessary engineering developments. We consider that the requirements of the GRA have been adequately met. We believe, however, that there is scope to refine the level of detail and correlate areas of future work with commitments within the ESC and other documentation. Furthermore, any forward programme should take account of our recommendations, FIs and requirements we have raised as part of our 2011 ESC review and our permitting process. We have raised an FI to this effect.

We have considered how the 2011 ESC has advanced and taken account of learning from the 2002 ESCs. We have concluded that the 2011 ESC presents a more coherent and much improved case for the continued operation of the LLWR. However, LLW Repository Ltd should make sure that learning from previous assessments, in particular examples of best practice and relevant research and development, are carried through to future ESCs.

Overall, we conclude that LLW Repository Ltd has taken the expectations of the GRA into account and that the 2011 ESC represents a proportionate response. To guide continued improvement of the ESC, we have raised one recommendation related to Requirement 3 of the GRA (Environment Agency 2015a).

4.5. Requirement R4: Environmental safety culture and management system

The GRA states that:

'The developer/operator of a disposal facility for solid radioactive waste should foster and nurture a positive environmental safety culture at all times and should have a management system, organisational structure and resources sufficient to provide the following functions: (a) planning and control of work; (b) the application of sound science and good engineering practice; (c) provision of information; (d) documentation and record-keeping; (e) quality management.'

We have reviewed the diverse areas this requirement covers and how they are addressed within the 2011 ESC, supported by a number of IRFs responded to by LLW Repository Ltd.

Regarding developing a positive environmental safety culture we are satisfied that LLW Repository Ltd has achieved this. This has been adequately demonstrated through, for example, commitments stated in its Environment, Health, Safety and Quality Policy, provision of training, communications on environmental matters, events and provision of adequate environmental resource. We asked

[8] Features, events and processes, or FEPs, are any factors that may influence the disposal system and/or the development of the ESC.

the company to clarify how the LLW Repository Ltd Board supported this culture and 'lead from the top'. We were reassured that the Board were adequately engaged, received and sought relevant information and were independently informed by an independent member of the Board.

We are reassured that LLW Repository Ltd's management system is well-established and mature. It has developed from systems previously used on the Sellafield site, but has moved on significantly since then into a stand-alone, site-specific system. We also had opportunity to audit and inspect the system through our ongoing regulation of the site, for example a management arrangements audit in 2013. These activities have provided confidence that the management system is generally effective in achieving its goals, consistent with the GRA's expectations.

We agree with LLW Repository Ltd that its management system is comprehensive and fully integrated. It is clearly documented, with requirements flowing from a top level management system manual through to specific site procedures and environment, health, safety and quality role and post specifications. We support the fact that ESC specific project management arrangements were put in place when the 2011 ESC was being developed, including a dedicated project team, project manager, project execution plan and other quality, peer review and engagement procedures.

We have examined a number of specific areas regarding LLW Repository Ltd's management systems, organisational structure and resources, including:

- Organisational structures: We found these to be clear and reasonable, providing an unbroken chain of responsibilities and accountabilities from staff through to the Managing Director and Board. We welcome the fact that the organisation was revised following a significant review in 2008, ensuring it was better aligned with its future mission and responsibilities.
- Management of change processes: These were demonstrated to be in place.
- Resourcing, competency, knowledge management and succession planning: These management processes, such as organisational baseline documents, succession planning and review processes were demonstrated to be in place. We sought reassurance in this area regarding the maintenance of ongoing ESC knowledge and received a satisfactory response, pointing to measures taken to build strength in the ESC Project Team. However, due to the significance of this area to the ESC, we have made a number of recommendations.
- Processes to ensure learning and continuous improvement: These were in place and included an Operational Experience Feedback process. LLW Repository Ltd provided examples where learning was applied. We consider that there will be significant learning potential from both the development of the 2002 ESCs and 2011 ESC and we raised an FI on this basis.
- Work supporting the 2011 ESC: We found that this work was suitably controlled by the Integrated Management System, which has relevant accreditations to British and international standards. Also, specific ESC documentation was in place to supplement the wider management system where relevant.
- Compliance with limits and conditions in the environmental permit: We found this area to be suitably controlled by a number of procedures, supported by WAC and an Environmental Clearance Certificate and supporting documentation. However, we raised an FI requiring LLW Repository Ltd to develop a new low level waste tracking system, which meets the needs of the current ESC, waste acceptance criteria and environmental permit and to make sure that all ESC related records are properly managed.
- Modification and change processes: We support the fact that these change processes are based on established nuclear safety case processes. We identified that relevant procedures were in place to support this, supported by an implementation plan.
- Records management: We found adequate systems in place, supported by an audit we carried out in 2011. Due to the importance of collating a comprehensive set of ESC records, many of which were generated by contractors, we raised an FI requiring all relevant records to be brought 'in-house' under the direct control of LLW Repository Ltd, wherever practicable.
- Quality management: We welcome the fact that LLW Repository Ltd operates a management system accredited to relevant standards (BS EN ISO 9001:2008, BS EN ISO 14001:2004 and OHSAS 18001:2007). LLW Repository Ltd operates a reasonable programme of auditing.

Following an IRF seeking assurance that the 2011 ESC and its development is adequately audited, further improvements were made to this programme so that the ESC project and other areas, would be suitably quality assured.

- Application of sound science and good engineering practice: We are satisfied that sound science and good engineering practice has generally been used, with good practice demonstrated in some areas. This was achieved through a number of ways such as by using suitably qualified and experienced staff, using peer review and being involved in national and international fora. We welcome the fact that LLW Repository Ltd continues to strengthen its ESC Project Team.
- Passive safety: We are satisfied that LLW Repository Ltd has applied principles of passive safety as far as reasonably practicable.
- Peer review: We welcome the use of both a UK based independent peer review group process and an international peer review group. We consider the outputs of these processes have been beneficial. We support LLW Repository Ltd's intent to maintain peer review processes when further developing the ESC. We do, however, consider that there could be a number of improvements to the process and have made recommendations accordingly.

Overall, we are satisfied that LLW Repository Ltd operates with a positive environmental safety culture and has a suitable management system in place, in accordance with Requirement R4 of the GRA. However, we noted a number of areas for potential future improvement to the ESC and processes supporting it, so that it continues to meet the requirements of the GRA. We have, therefore, raised a number of FIs and recommendations related to Requirement R4 (Environment Agency 2015a and 2015g).

4.6. Requirement R5: Dose constraints during the period of authorisation

The GRA states that:

'During the period of authorisation of a disposal facility for solid radioactive waste, the effective dose from the facility to a representative member of the critical group should not exceed a source-related dose constraint and a site related dose constraint.'

'The UK government and devolved administrations have directed the environment agencies to have regard to the following maximum doses to individuals which may result from a defined source, for use at the planning stage in radiation protection:

- 0.3 mSv per year from any source from which radioactive discharges are made
- 0.5 mSv per year from the discharges from any single site'

Supplementary guidance to the GRA, resulting from the implementation of the Groundwater Directive, specifies an additional dose guidance level of 0.02 mSv y^{-1} for doses arising from groundwater during the period of authorisation (Environment Agency 2012).

The period of authorisation includes the operational period, which LLW Repository Ltd states will continue up to 2080 AD in the case of the reference disposal area or 2130 AD in the case of the extended disposal area, and a subsequent period of active institutional control. Active institutional control is expected to last for at least 100 years after disposals have ended (and a maximum of 300 years), and includes management of the site and monitoring. In accordance with the GRA, LLW Repository Ltd applied the dose assessment criteria when assessing doses to the relevant critical groups for the period of authorisation, assuming a 100 year period of active institutional control. Thereafter, the company applied the appropriate risk and dose guidance levels to assess radiological impacts to humans (see sections 4.7 and 4.8).

LLW Repository Ltd discusses potential strategies for the active institutional control period in Penfold et al. (2010). However, final decisions about the manner of closing the LLWR facility and subsequent active institutional control cannot be made now or in the near future (unless a decision was taken to close the facility with immediate or early effect). We recommended that action should not be taken now that could make particular approaches to closure and subsequent active

institutional control more difficult. Producing and keeping relevant records throughout the operational period will be essential to support the future development of appropriate strategies.

For the period of authorisation, LLW Repository Ltd assessed the implications of radioactive discharges to air, surface water and groundwater and direct radiation on humans and biota. We consider that these assessments cover an appropriate range of potential exposure scenarios.

LLW Repository Ltd has used its measured discharges and environmental concentrations to provide evidence that the dose constraints have been met in the past (LLW Repository Ltd 2011k). The company has assessed the impacts from likely future discharges during the period of authorisation to show that future radiological impacts will be generally below the dose constraints, even when cautious assumptions are made and when the peak assessed annual doses are combined for each possible exposure pathway. This is conservative since different exposure pathways lead to peak doses in different locations at different times and, therefore, the summed peak annual doses are not expected to be realised.

Only peak doses resulting from direct radiation are projected to potentially exceed the source-related dose constraint of 300 μSv y^{-1}, with a maximum annual dose calculated of 600 μSv for a theoretical future resident that lives off-site immediately adjacent to Vault 13. As noted in section 3.6, we agree with LLW Repository Ltd that this scenario is not realistic and that the dose constraint is unlikely to be exceeded in practice. In future, direct radiation exposures will be managed by an appropriate waste emplacement strategy and will be monitored and reported. Assuming continued regulation of the site equivalent to today's standards, these exposure scenarios would not be permitted without further mitigation measures to reduce off-site doses.

LLW Repository Ltd notes that there is generally a decreasing trend in assessed impacts throughout the period of authorisation, mainly due to a combination of decreasing activity in disposals as a result of radioactive decay and the placement of the final capping system. The calculations are also conservative in that engineering measures have largely been neglected. The emplacement of closure engineering will further reduce the impact of the LLWR on the surrounding environment.

We accept LLW Repository Ltd's approach, reasoning and conclusions and consider that it has met Requirement R5 and the supplementary guidance. However, given the limitations in all environmental modelling projections, it would not be appropriate to rely entirely on this assessment. Instead, we expect site monitoring to continue throughout the period of authorisation and be able to identify any significant changes to existing contamination levels. We have made a number of recommendations to LLW Repository Ltd on areas for future improvement of its dose assessment for the period of authorisation and better integration between the period of authorisation and post-closure assessments (Environment Agency 2015e).

4.7. Requirement R6: Risk guidance level after the period of authorisation

The GRA states that:

'After the period of authorisation, the assessed radiological risk from a disposal facility to a person representative of those at greatest risk should be consistent with a risk guidance level of 10^{-6} per year (that is 1 in a million per year).'

Supplementary guidance to the GRA, resulting from the implementation of the Groundwater Directive, specifies that we shall require the developer or operator of a radioactive waste disposal facility in all cases to show that the radiological risk to members of the public through the groundwater pathway after the period of authorisation of the facility is consistent with, or lower than, a risk guidance level of 10^{-6} per year (Environment Agency 2012).

Our risk guidance level is our assessment standard for the expected natural evolution of the disposal facility over time. It does not apply to potential human intrusion events that bypass the engineered barriers to allow exposure to the waste. Future human intrusion is discussed in section 4.8. The value of 10^{-6} per year is consistent with advice given by the Health and Safety Executive (HSE) as 'a very low level of risk'. This should be used as a guideline above which people are

prepared to tolerate risks to secure the benefits from the activities giving rise to the risks and below which risks are broadly accepted by society because they are generally regarded as insignificant (HSE 2001).

The assessed radiological risk from a potential exposure situation corresponds to the product of the estimated effective dose that could be received, the estimated probability that this dose will be received and the estimated probability that harm would occur as a consequence to the person exposed. LLW Repository Ltd applies a dose to risk conversion factor of 0.06 per Sv to estimate the probability that serious health effects would occur as a consequence to the person exposed. This is in line with recommendations in paragraph 6.3.15 of the GRA.

LLW Repository Ltd assessed impacts associated with the groundwater pathway, gas pathway (radon and C-14) and coastal erosion in the post-closure period for comparison against the risk guidance level. The company assumes that the post-closure period begins 100 years after disposals have stopped. The assessment incorporates the expected evolution of the system over time, taking into account uncertainties, including degradation of engineered barriers, hydrological changes due to climate change and coastal erosion. Coastal erosion is represented firstly as a reduction in the distance between the LLWR and the coast and secondly as physical erosion of the vaults and trenches.

Managing uncertainties is an important consideration in the radiological assessment. As discussed in paragraphs 6.3.23 to 6.3.29 of the GRA, we expect LLW Repository Ltd to consider those uncertainties that can be quantified within the numerical risk assessment. We also expect the company to take into account those uncertainties that cannot be reliably quantified when developing the ESC. LLW Repository Ltd has considered uncertainties depending on whether they fall into one of three categories:

- Scenario uncertainty: treated by assessing a 'reference case', which is the most likely future for the LLWR and its environment and a range of alternative scenarios, including alternative inventories, near field biogeochemical evolution models, alternative hydrogeological conceptualisations, alternative coastal erosion rates and mechanisms and a range of potential exposed groups.
- Model uncertainty: treated using alternative conceptual models and computer codes using different temporal and spatial scales and complexities to identify the main features and processes affecting contaminant releases from the LLWR, migration within the environment and uptake by humans and biota.
- Parameter uncertainty: treated by reviewing uncertainties in important parameter values and assessing variations within ranges that encompass the uncertainty in process understanding and variability at appropriate scales.

LLW Repository Ltd has documented these uncertainties in a FEPs and uncertainty tracking system (LLW Repository Ltd 2013c). In assessment calculations LLW Repository Ltd has used a range of alternative deterministic calculation cases to assess the effects of different important parameters and different models and scenarios. The company included only one probabilistic calculation presented in the 2011 ESC for the groundwater pathway, the 'well scenario'. This was not included in the recent update that takes into account the effects of complexants. Although we consider that this approach is consistent with international practice and meets the requirements of the GRA, we recommended that LLW Repository Ltd improves how it documents uncertainties (see section 4.4). We also recommended that it makes greater use of probabilistic methods in future assessments, where appropriate. We consider that in many cases probabilistic assessments are more appropriate for making comparisons because the impacts of values sampled from the tails of parameter distributions are taken into account. Probabilistic calculations can also enable variations in several parameters and combinational effects to be assessed more readily and expressed as the expectation value.

For most calculations, LLW Repository Ltd assumes that there is a probability of 1 of a person receiving the dose. We consider this an appropriate and conservative assumption. Only for the groundwater pathway, well calculations is the probability of the existence of a well taken into account. The company elicited the probability of existence of a well using evidence of land use along the Cumbrian coast. It recognises that it is relatively unlikely that a well would be drilled in

the strip of land between the LLWR and the coast and that the area will reduce over time due to coastal erosion. After the period of authorisation, the company take no credit for the designation of the land between the LLWR and the coast as a Special Conservation Area and Site of Special Scientific Interest.

LLW Repository Ltd has demonstrated that radiological risks associated with the reference case assumptions for the post-closure period fall below the risk guidance level, as summarised by Cummings (2013). Only for several unlikely 'what if' variant calculations are the radiological risks projected to exceed the risk guidance level. However, we consider that these cases should not be given dominant consideration for regulatory purposes (see section 2.3.4 of Environment Agency 2015e).

We consider that LLW Repository Ltd has taken into account a reasonable range of cautious assumptions about future scenarios and human habits and behaviour. We have no reason to believe that the company's assessments have significantly underestimated potential radiological impacts (doses and risks). However, we consider that the company should make efforts to manage uncertainties better and make sure that all important uncertainties, some of which may currently be implicit, are made explicit in its register of significant uncertainties.

In summary, we consider that LLW Repository Ltd has demonstrated that radiological risks in the post-closure period associated with the most likely evolution of the LLWR and a suitable range of exposure pathways and situations will meet GRA Requirement R6 and the supplementary guidance relating to the implementation of the Groundwater Directive. However, we have made a number of recommendations to LLW Repository Ltd on areas for future improvement of its post-closure radiological risk assessment (Environment Agency 2015e).

4.8. Requirement R7: Human intrusion after the period of authorisation

The GRA states that:

'The developer/operator of a near-surface disposal facility should assess the potential consequences of human intrusion into the facility after the period of authorisation on the basis that it is likely to occur. The developer/operator should, however, consider and implement any practical measures that might reduce the chance of its happening. The assessed effective dose to any person during and after the assumed intrusion should not exceed a dose guidance level in the range of around 3 mSv/year to around 20 mSv/year. Values towards the lower end of this range are applicable to assessed exposures continuing over a period of years (prolonged exposures), while values towards the upper end of the range are applicable to assessed exposures that are only short-term (transitory exposures).'

We expect assessment of a range of potential radiological exposures to which possible intruders to the repository could be exposed. A range of possible exposure cases must be assessed, including exposure to any gaseous emissions such as radon (GRA paragraph 6.3.39). These scenarios should assume that a potential intruder either has no prior knowledge of the disposal facility or have knowledge of the existence of underground workings but no understanding of what they contain (GRA paragraph 6.3.41).

LLW Repository Ltd identified a range of possible human intrusion events and more prolonged exposure situations. This was based on geotechnical practices and credible future uses of the site, assuming the site is no longer protected by the planning regime and/or the presence and nature of the disposal facility is forgotten. The company classified human intrusion events into two categories: those that could happen any time after the end of the period of authorisation (such as investigation of the site or occupancy following such an event); and those that can only happen after waste has been exposed by coastal erosion (such as scavenging and recovering materials).

LLW Repository Ltd assessed doses from short-term exposure, which people directly involved in intrusion activities such as borehole drilling and construction would receive. The company also assessed annual doses to people exposed to environmental contamination over a longer period

caused by the intrusion, such as inhabiting a dwelling or managing a smallholding located on top of the facility. This approach to assessing human intrusion is consistent with Requirement R7.

LLW Repository Ltd has demonstrated that doses to all the identified potentially exposed groups are consistent with the appropriate dose guidance level. The 2011 ESC also notes that the final engineered cap will contain a 600 mm thick layer of compacted cobbles designed to discourage intrusion into the waste by humans, burrowing animals and deep-rooting plants. However, the assessment calculations do not take any credit for this. We consider that LLW Repository Ltd has made a reasonable range of cautious assumptions about future scenarios and human habits and behaviour. We have no reason to believe that the company's assessments have significantly underestimated potential doses.

Given the low doses associated with these intrusion events, LLW Repository Ltd has not identified any event that could cause 'severe deterministic injury'[9] to individual body tissues. This is consistent with the requirements of the GRA (paragraph 6.3.40).

For discrete items of waste and radioactive particles that contain a significant burden of radioactivity, which might give rise to a committed effective dose in the range of 3 to 20 mSv y^{-1} if encountered on a beach following coastal erosion in the future, LLW Repository Ltd has included further waste acceptance controls in the latest version of the WAC (LLW Repository Ltd 2015). This assessment was in line with our supplementary guidance to assessors on the disposal of discrete items and particles (Smith 2014). The company's proposed emplacement strategies will also help to reduce assessed doses and risks for certain scenarios.

In summary, we consider that LLW Repository Ltd has demonstrated that doses in the post-closure period associated with a credible range of intrusion events will meet GRA Requirement R7. However, we have noted a number of areas for potential future improvement to the human intrusion assessment, made a number of recommendations and raised several FIs related to Requirement R7 (Environment Agency 2015e and 2015g).

4.9. Requirement R8: Optimisation

The GRA 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 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.'

LLW Repository Ltd carried out a wide range of optimisation studies when developing the 2011 ESC. The company used the output from these studies to demonstrate that the LLWR and the site development plan are optimised with respect to:

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

LLW Repository Ltd's optimisation process needs to demonstrate that selected options will be ALARA with reference to the dose constraints and the dose and risk guidance levels. As discussed in the sections above, we consider that LLW Repository Ltd has appropriately used these constraints and guidance levels to demonstrate that the LLWR will protect human health during the period of authorisation and afterwards. In determining compliance with GRA Principle 2 and Requirement R8, we have concluded that the company has used these constraints and guidance levels appropriately in the optimisation studies supporting the 2011 ESC.

[9] A severe deterministic injury is an injury that is directly attributable to the radiation exposure, that is irreversible in nature and that severely impairs health and/or the quality of life of that individual.

LLW Repository Ltd has demonstrated that past disposals to the facility are now optimised. However, further detailed work is ongoing to identify and implement specific improvements in accordance with best available techniques. This includes work examining improvements to the trench cap, investigating leachate management options and investigating the options for the management of discrete items that may have been disposed of in the vaults and trenches in the past.

LLW Repository Ltd has identified that its container design needs to be optimised further. We have raised a number of FIs that require the company to explain and demonstrate how the optimised container will protect the waste and help minimise cap settlement.

LLW Repository Ltd has identified a range of improvements to the WAC and operational procedures that we consider can meet the optimisation objectives in the 2011 ESC. These are suitable for managing future disposals and managing the site during the operational and post-closure period.

We consider that the site development plan is optimised at a conceptual level and sufficiently reflects the repository's level of development. Before closure engineering (cap and cut-off wall) and any further vaults are constructed, we will expect further detailed optimisation to take account of material performance and other more detailed design aspects and assessments such as constructability.

Following on from the optimised design in the 2011 ESC, LLW Repository Ltd will in future need to provide a framework for the development and implementation of more detailed and further optimised engineering designs. To help achieve this LLW Repository Ltd has developed a comprehensive forward engineering programme. This includes further engineering development work and the substantiation of the performance of various components of the engineered barrier system, both individually and together. This will support ongoing work to continue to demonstrate that the design remains optimised. Due to the significance of this area of work to the overall ESC and safety of the site we have raised a number of FIs detailing our expectations for further engineering development. We will work with LLW Repository Ltd as it develops its engineering further, making sure it continues to meet our expectations.

We consider that LLW Repository Ltd has provided sound arguments and reasoning for all the major optioneering decisions and that an optimisation case has been made that meets Requirement R8 (and Principle 2) of the GRA. However, the optimisation process itself was often unclear and poorly documented. In the future, we expect the optimisation process to continue on an iterative basis. We consider it important that all optimisation decisions are appropriately documented and linked to the wider repository concept.

In summary, we consider that the site development plan has been appropriately optimised. The 2011 ESC has been informed by sound arguments and reasoning for all the major optioneering decisions. We expect the optimisation process to continue throughout construction, operation and restoration. We noted a number of areas for potential future improvement to the ESC and the processes supporting it, so that it continues to meet the requirements of the GRA. We have, therefore, raised a number of FIs and recommendations related to Requirement R8 (Environment Agency 2015d and 2015g).

4.10. Requirement R9: Environmental radioactivity

The GRA states that:

'The developer/operator should carry out an assessment to investigate the radiological effects of a disposal facility on the accessible environment both during the period of authorisation and afterwards with a view to showing that all aspects of the accessible environment are adequately protected.'

When the GRA was issued, there were no internationally established criteria for determining radiological protection of the environment. We, therefore, recommended that a developer/operator should carry out an assessment and 'draw conclusions about the effects of a disposal facility on the accessible environment using the best available information at the time of the assessment' (GRA paragraph 6.3.74).

In the 2011 ESC, LLW Repository Ltd estimated radiological doses to non-human biota living in the terrestrial, freshwater and marine environments near the LLWR during the period of authorisation and post-closure period. This includes wildlife living in the Drigg Coast Special Area of Conservation and Site of Special Scientific Interest, which lies adjacent to the western site boundary. LLW Repository Ltd screened doses against a generic screening criterion of 10 µGy h^{-1} in accordance with the recommendations of a European Union EURATOM Framework 6 funded 'Protection of the Environment from Ionising Radiation in a Regulatory Context' (PROTECT) project (Andersson et al. 2008). We consider that this screening dose rate is appropriate to use in situations where doses from other discharges (for example other nuclear licensed sites such as Sellafield) are uncertain. It is well below the 40 µGy h^{-1} action level relating to total impacts from all permitted discharges (aerial and liquid discharges) that may affect a protected site such as the Drigg Coast Special Area of Conservation that we have defined to protect the whole ecosystem (Environment Agency 2009).

LLW Repository Ltd has assessed the effects of radioactive discharges on non-human biota using the Environmental Risks from Ionising Contaminants: Assessment and Management (ERICA) Integrated Approach (Beresford et al. 2007a). This provides a framework for assessing the effects of ionising radiation on the structure and function of ecosystems, which was also developed under EURATOM Framework 6. The assessment was based on a combination of monitored environmental concentration data (period of authorisation) and projected future environmental concentrations (post-closure period) associated with discharges of radioactive gas and leachate from the LLWR. The company also assessed impacts associated with exposure to waste in the cliff, coastal and marine environment following coastal erosion of the repository, including exposure to undiluted waste in the cliff.

Using this approach, LLW Repository Ltd demonstrated that the present day effects on biota from the LLWR are at levels below concern and that the effects are unlikely to increase significantly during the period of authorisation. Similarly, the company has demonstrated that releases of radionuclides from the LLWR in the post-closure period via all groundwater pathways and the gas pathway are projected to give rise to dose rates to non-human biota that are below the screening criterion of 10 µGy h^{-1}. During the potential future coastal erosion of the LLWR dose rates to some organisms may exceed 10 µGy h^{-1}. Plants and invertebrates living on the storm beach could receive dose rates slightly higher than 100 µGy h^{-1}. However, we have reviewed the evidence LLW Repository Ltd submitted on the relative radio-insensitivity of these species (Jackson 2013) and we have concluded that these doses will cause no perceptible harm.

In summary, we consider that LLW Repository has demonstrated that the radiological effects of the LLWR on the accessible environment both during the period of authorisation and afterwards are low enough and that the environment is adequately protected. We conclude that GRA Requirement R9 has been met, although we have made a number of recommendations to LLW Repository Ltd to improve its non-human biota assessment so that it continues to meet the requirements of the GRA (Environment Agency 2015e).

4.11. Requirement R10: Protection against non-radiological hazards

The GRA states 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.'

The GRA does not specify any specific standards for assessing the non-radiological hazards associated with disposals. Instead, it requires that a level of protection should be provided that is 'no less stringent' than would be provided by the nationally accepted standards for disposing of hazardous waste (GRA paragraph 6.4.2). The principle of optimisation only applies to radiological risks, however, 'adequate protection against non-radiological hazards needs to be maintained when optimising for radiological risks' (GRA paragraph 6.4.5).

Our assessment of the repository engineering design looked at whether it provides a level of protection against non-radiological hazards that is no less stringent than nationally accepted engineering design standards. LLW Repository Ltd has achieved this in the 2011 ESC by

comparing the level of containment and barrier design to that set out in the Landfill Directive (European Union Directive 99/31/EC). It has been able to demonstrate that the engineering design is capable of providing a level of engineering (and environmental protection) against non-radiological hazards that is no less stringent than that required by the Landfill Directive. We consider that the 2011 ESC appropriately took into account the potentially conflicting radiological and non-radiological design objectives and was able to present a repository design which is able to provide both radiological and non-radiological protection over the entire life of the LLWR. We consider that an equivalent degree of protection to that provided by a non-radioactive landfill will be provided by the final engineered cap and, in the interim, improvements to the trench cap.

The composition of the non-radiological component of the LLWR inventory is still very uncertain. This uncertainty is greater than the uncertainty in the radiological component of the inventory and reflects the lack of relevant waste characterisation and the limitations of past waste classification systems. We recognise that the information available is limited and support LLW Repository Ltd's ongoing liaison with consigners and the NDA to better understand the non-radiological component of disposals.

To demonstrate how it meets Requirement R10 and the requirements of the Groundwater Directive, LLW Repository Ltd presented a non-radioactive contaminant assessment for the groundwater pathway based on the radiological assessment model. The company does not formally assess the effects of uncertainty in the non-radiological component of the inventory; however, it uses conservative assumptions in the assessment source term model, which we considered appropriate. As discussed in section 3.6, LLW Repository Ltd projects that, although concentrations of hazardous substances and non-hazardous pollutants in the groundwater remain low throughout the period of authorisation, compliance limits could potentially be exceeded for some substances after several hundred years post-closure.

In our review of the non-radioactive contaminant assessment, we took into account both regulatory factors and the significant uncertainties associated with the assessment, in particular the trench and vault waste source terms. We concluded that, for the purposes of the Groundwater Directive and EPR10, which implements the Groundwater Directive, all necessary and reasonable measures have been taken to prevent the input of any hazardous substances to groundwater and to limit the input of non-hazardous pollutants so as to make sure these inputs do not cause pollution to groundwater. This conclusion takes account of the GRA, the requirements of EPR10 and the extended timeframe over which non-radiological discharges are predicted to happen. It is based on a proportionate approach, taking account of the requirement to optimise for radiological aspects.

Although we are satisfied that the LLWR currently meets the necessary requirements, to make sure LLW Repository Ltd continues to demonstrate that groundwater is protected, we require the company to produce an updated non-radiological hydrogeological risk assessment before the end of 2017. This updated assessment should have full regard to requirements of the GRA and Environment Agency guidance on hydrogeological risk assessments for landfills.

LLW Repository Ltd carries out a monitoring programme for non-radioactive contaminants in leachate, groundwater and surface water. Data from this programme have been used to inform the non-radiological groundwater assessment. We require LLW Repository Ltd to continue to maintain a non-radioactive monitoring programme that can support future non-radiological hydrogeological risk assessments and understanding of the behaviour of the repository (Environment Agency 2015c).

The 2011 ESC includes non-radiological assessments for the human intrusion and coastal erosion scenarios. LLW Repository Ltd demonstrates that impacts to humans associated with exposure to non-radioactive contaminants during these scenarios are unlikely to cause harm. We consider that the assessments provide useful quantification of the nature and significance of the non-radiological hazards and their effects during the operation of the LLWR and after, although we note that such assessment would not normally be required for a hazardous waste landfill. Unless this situation changes, these assessments will be optional and we will not require them to be included in future versions of the ESC.

Through routine monitoring for gases generated from the waste in the trenches LLW Repository Ltd has identified the presence of hydrogen, methane, carbon dioxide and hydrogen sulphide. We

agree with LLW Repository Ltd's assessment that the hazard from gas produced in the trenches and vaults is low. The main significance of these gases is their potential to act as a carrier for radioactive C-14 gas, which is considered in the radiological assessment.

In summary, we consider that the current assessment of the non-radiological inventory adequately demonstrates that GRA requirement R10 is being met, although we noted a number of areas for improvement and we have made a number of recommendations and raised one FI. In particular, we expect LLW Repository Ltd to consider more closely our guidance on conventional landfill hydrogeological assessment (Environment Agency 2011).

4.12. Requirement R11: Site investigation

The GRA 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.'

We are satisfied that LLW Repository Ltd has appropriately characterised the LLWR and its setting using both on-site and, to a lesser extent, off-site geological and hydrogeological information from multiple investigations. The heterogeneous nature of the Quaternary deposits underlying the LLWR means that it may not be possible to characterise precisely the layout of low and high permeability lithologies. The geological interpretation and resultant modelling of the Quaternary geologies is considered appropriate. There will always be a significant level of uncertainty about how groundwater within these geologies behaves at a small scale (10s to 100 metres). Because of this complexity, further site investigation may not significantly reduce this uncertainty. Apart from the land between the site and the coastline, where access is difficult, we consider that the LLWR and the surrounding area have been adequately investigated in support of the 2011 ESC.

We expect future site investigation information to continue to support the conceptualisation of the site, to inform the repository design and the future monitoring programme. As well as producing a forward programme designed to investigate the main uncertainties and align with the outputs of the ESC, we would expect future site investigation to be carried out on an opportunistic basis and to support the construction of future vaults.

LLW Repository Ltd used an iterative approach to develop the geological and hydrogeological conceptual models and the groundwater flow model. LLW Repository Ltd does not provide detailed proposals for updating these models in the forward programme. We expect LLW Repository Ltd to continue to iterate and develop the current geological and hydrogeological models to support future updates to the ESC. Where appropriate, the forward programme should be supported with site characterisation information. We set out our requirements for a forward programme in an FI.

The conceptualisation of the site used to build the 2011 ESC drew upon an appropriate range of information from the site. As the ESC matures and more site performance information becomes available, we expect LLW Repository Ltd to make increased use of site-derived information. We have asked the company to provide more detail on how it will use monitoring to support the information needs of the ESC.

Site investigation information also formed an important part of the coastal studies programme, which covers conceptualisation and characterisation of the coastal landscape and coastal processes affecting the evolution of the coastline. This aspect of the site investigation programme is not as well established as the information used to inform the groundwater pathway assessment. We expect LLW Repository Ltd to continue to collect and use site investigation data to improve understanding of future coastal change.

We consider that LLW Repository Ltd has used geological, hydrogeological and geotechnical data appropriately to inform the engineering concept and design. However, the conceptual nature of the engineering design means that the design has not yet been fully developed in detail. As future vaults are constructed site investigation data will be needed to inform the future design. As the engineering design is developed further and constructed, we expect to see a greater use of site-derived information to support the engineering performance assessment and substantiate the

projected long-term behaviour and performance of the basal drainage layer and geological barriers.

We conclude that LLW Repository Ltd has used information gained from site investigation appropriately to inform the geological and hydrogeological conceptualisation of the LLWR and its surrounding area, support the projections of coastal erosion and to inform the engineering concept and design. We consider that LLW Repository Ltd has adequately addressed Requirement R11, although we have put forward several recommendations that it should address so that it continues to meet this requirement (Environment Agency 2015c).

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

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.'

In our review of the LLWR site development plan and engineering forward programme, we have taken into account both GRA Requirement R12 and consistency with engineering good practice. We are confident that LLW Repository Ltd has developed an appropriate conceptual engineering design and appropriate plans for operating and eventually closing the repository.

The presented design incorporates systems capable of providing the required safety objectives such as isolation and containment through construction, operation and closure. However, we note that the design does need to be developed and substantiated further before construction, to make sure it will meet the required performance objectives and those assumed within the 2011 ESC. For example, the container condition surveys LLW Repository Ltd carried out identified a number of mechanisms that could influence the long-term performance of the disposal and closure engineering systems (Jefferies 2012). Once identified, LLW Repository Ltd instigated an appropriate investigation programme, which has identified operational and design improvements. LLW Repository Ltd has committed to carry out these improvements, which address optimisation of the ISO freight containers, waste stacking and the rate of waste capping (or protection).

The proposed phased sequence of emplacing closure engineering over the waste provides the flexibility needed to take account of uncertainties in the rate and volume of LLW disposals. Although we consider the proposed capping sequence offers an appropriate initial proposal for the phasing of closure engineering, we believe that the phasing will probably need to be adjusted over time. We consider adjustments are likely due to changes in the input rates of waste, the possible need for work to further protect the interim trench cap and the need to provide cover over waste more frequently than planned within the 2011 ESC to minimise container degradation. We are satisfied that the design and operational plans are flexible enough to accommodate these changes.

We are also satisfied that reasonable arrangements are in place to fund the closure of the facility. The UK government funds decommissioning activities associated with nuclear liabilities via the NDA. This includes waste disposal activities at the LLWR.

We consider that LLW Repository Ltd has adequately addressed Requirement R12 of the GRA. We agree that the presented engineering design concept meets regulatory expectation. However, we and LLW Repository Ltd identified the need for a substantial forward engineering programme of work to implement the repository design. We set out our expectations for the forward programme in a number of recommendations and FIs (Environment Agency 2015d and 2015g). Before beginning site restoration engineering works, we expect LLW Repository Ltd to progress this forward programme of work so that the ESC continues to meet the requirements of the GRA.

4.14. Requirement R13: Waste acceptance criteria

The GRA states that:

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

LLW Repository Ltd has defined a series of WAC, which cover controls on waste form and physical composition of waste, biogeochemical properties of waste, controls to limit the radiological and hazardous inventories and implementation arrangements such as transport and handling (some elements of the latter, for example packaging and transportation arrangements, are not covered by our regulation of the site but instead largely by the Office for Nuclear Regulation). The WAC are for waste producers and LLW Repository Ltd to use so they can assess waste for potential disposal at the LLWR and to manage any subsequent disposals. They are also provided to regulators and other interested parties to show how waste accepted for disposal at the site are controlled. They consider all the necessary characteristics of the waste required to ensure the safe operation and long-term environmental performance of the site.

We expect WAC to be managed in line with the latest ESC assessments. LLW Repository Ltd has done this and, as a result, proposed a number of changes to the WAC. Particularly significant are the updated radiological capacity calculations based on the results of the 2011 performance assessment (and subsequent updates). A 'sum of fractions' approach to managing radiological capacity over the lifetime of the site has been proposed and we believe it has been appropriately implemented within the waste acceptance process. LLW Repository Ltd has also instigated more stringent controls on the hazardous component of future disposals, including a capacity-based approach for significant substances, and controls on asbestos.

Some other important changes to the WAC include:

- Requirements for extra information on disposals, both radiological and non-radiological content. We welcome this as a way of improving the robustness of the waste inventory in the future.
- Revisions to packing and information requirements related to the generation of total potential voidage within the waste containers. We welcome this as an improved way of reducing voidage within containers and improving information available to manage this issue.
- Proposals to remove current restrictions on the disposal of any complexing or chelating agents. We are satisfied that the assessments presented within the Developments report support this (LLW Repository Ltd 2013a).

We consider that the changes to the WAC are consistent with the outcomes of the 2011 ESC and subsequent updates. We believe these will be sufficient to achieve acceptable doses and risks to people and the environment. LLW Repository Ltd has introduced further controls on higher activity particulate materials and discrete items, which we believe are appropriate.

We note that, in advance of any variation to its environmental permit being granted, LLW Repository Ltd can only implement changes to the WAC that are consistent with the current environmental permit for the site. LLW Repository Ltd has implemented many of the changes proposed in the 2011 ESC in its latest version of the WAC (LLW Repository Ltd 2014). LLW Repository Ltd proposes to update the WAC further if its environmental permit is revised in future to reflect its full proposals in the current 2011 ESC and Developments report (LLW Repository Ltd 2011p and 2013b).

We have raised a number of recommendations and FIs to seek ongoing improvements to the robustness and implementation of the WAC (Environment Agency 2015a, 2015e and 2015g). We are satisfied that LLW Repository Ltd has put adequate plans in place to implement the WAC and associated procedures. We conclude that LLW Repository Ltd has met GRA Requirement R13.

4.15. Requirement R14: Monitoring

The GRA states that:

'In support of the environmental safety case, the developer/operator of a disposal facility for solid radioactive waste should carry out a programme to monitor for changes caused by the construction, operation and closure of the facility.'

LLW Repository Ltd has a substantial programme of monitoring that covers both environmental monitoring, for example discharges and hydrogeological parameters and performance of engineered barriers. The company carries out monitoring for different reasons, including to:

- demonstrate it is complying with its environmental permit
- develop baseline conditions
- demonstrate that the site is not giving rise to unacceptable risk to the environment
- demonstrate that the performance of the facility is consistent with assumptions in the ESC
- address significant uncertainties

This programme has been developed over the years the LLWR has been operating in order to meet the changing needs of the repository as it has been developed and changing regulatory requirements.

We consider that the current monitoring programme is appropriately aligned with environmental pathways and receptors and is carried out within a comprehensive quality framework. LLW Repository Ltd has mechanisms in place to make sure that it reviews the results of its monitoring programme regularly and takes any action, if necessary, to inform future versions of the ESC. We are satisfied that the site environmental monitoring programme is capable of providing appropriate information so that the repository's performance can continue to be assessed.

Future monitoring at the LLWR will play an important role in increasing understanding and reducing uncertainties in a number of important areas, including:

- characterisation of trench leachate, in particular to determine the presence of complexants and colloids and better understand the non-radioactive component of the leachate
- evolution of the near field and supporting the further development of near field models
- groundwater flow and contaminant migration in the groundwater
- evolution of the coastline
- performance of components of the engineered barrier system

LLW Repository Ltd presents the current environmental monitoring programme (LLW Repository Ltd 2011j) together with a long-term monitoring strategy covering the period of authorisation (Hayes et al. 2011) in the 2011 ESC. Although the proposals put forward in the long-term monitoring strategy seem reasonable, we considered that the main body of the 2011 ESC had not appropriately integrated, informed and taken account of them. Since issuing the 2011 ESC, LLW Repository Ltd has done further work to identify monitoring objectives and align the monitoring strategy with the ESC. We expect the company to maintain a long-term monitoring and sampling strategy that is capable of supporting the ESC. We have raised an FI asking LLW Repository Ltd to make sure that it uses the programme appropriately to reduce uncertainties in the ESC. We have raised further FIs on future monitoring requirements in some significant areas, including targeted monitoring of the tritium plume in groundwater, non-radiological contaminant concentrations, colloids and complexants in the near field, coastal erosion over the long term and performance of the engineered systems.

The 2011 ESC needs to show how the various components of the disposal system help to ensure environmental safety. We consider that the environmental monitoring programme could be more closely aligned with this objective by demonstrating the performance of individual components of the disposal system, for example leachate and gas monitoring strategies, as well as the performance of the overall facility.

In summary, we consider that LLW Repository Ltd has designed and implemented a comprehensive environmental monitoring programme capable of demonstrating compliance with authorised discharge limits and radiological protection of members of the public during the period of authorisation. We consider that this programme is appropriate for demonstrating the LLWR is capable of operating within the parameters set out in the 2011 ESC and that the company has adequately addressed Requirement R14 of the GRA. However, we have put forward a number of recommendations and FIs that the company should address, so that it continues to meet this requirement to further improve the monitoring carried out (Environment Agency 2015c and 2015g).

We will work with LLW Repository Ltd to develop and help ensure continuous improvements of the site monitoring and characterisation programmes.

5. Forward programme

As discussed in section 4, we consider that LLW Repository Ltd has met all 14 requirements of the GRA and hence our 5 principles for solid radioactive waste disposal. However, the LLWR is an operational facility and will be subject to ongoing development, such as the possible construction of further disposal vaults, improvements to existing features (such as the interim trench cap) and emplacement of closure engineering. These developments will need to take into account new information and consider new technologies. Taking into account these challenges, we note that LLW Repository Ltd needs to maintain a substantial programme of work to make sure that the ESC remains a 'live' case and that the company continues to meet the requirements of the GRA. We expect LLW Repository Ltd to make sure that its ESC remains up to date and consistent with current best available techniques and to make use of sound science and engineering practice.

LLW Repository Ltd provided us with its forward programme of work (LLW Repository Ltd 2011o). We conclude that this forward programme is adequate and contains an appropriate level of detail at this point in time. However, the forward programme would benefit from further development in a number of areas, including, but not limited to, considering the output of our review of the 2011 ESC. In particular, we found it difficult to align the significant uncertainties identified in the 2011 ESC with the anticipated work programme over short, medium and long timescales. We have, therefore, asked LLW Repository Ltd to develop and update their forward programme further as a high priority, for completion in the short-term. Specifically, the forward programme should take account of:

- our review of the 2011 ESC, particularly our FIs and recommendations
- any development work that results from ‘new issues’ arising from our review of the 2011 ESC, such as issues associated with container voidage and particles/discrete items
- specific requirements stipulated in any varied environmental permit for the site and any development work required to support compliance with that varied permit
- any further input from the peer review group
- commitments made by LLW Repository Ltd within the 2011 ESC
- areas that LLW Repository Ltd identified as having scope for further improvement, such as near field modelling
- any necessary research and development, including the potential for development and testing of novel techniques and technologies
- information arising from ongoing monitoring of the site
- necessary activities to inform and improve site understanding
- significant uncertainties (for example, as tabulated in the FEP and uncertainty tracking system; LLW Repository Ltd 2013c)
- further developments in understanding resulting from operations at the LLWR against the 2011 ESC
- outputs from annual or periodic reviews of the ESC

We have outlined a number of specific requirements for further work in our FIs (Environment Agency 2015g) and recommendations (Environment Agency 2015b, 2015c, 2015d and 2015e).

One area where we recognise that LLW Repository Ltd needs to do a substantial amount of development is in repository engineering. In particular, this relates to substantiating the engineering performance of materials, further design optimisation and also finalising the designs for future vaults, closure engineering and individual barriers and systems. Our major requirements are summarised in section 3.4.1 and are collated in 6 FIs. We expect LLW Repository Ltd to demonstrate progress against these requirements well in advance of the next ESC and before the placement of closure engineering or the construction of any future vaults. Successful delivery against these issues will be critical for LLW Repository Ltd to refine the detail of the conceptual engineering design presented in the 2011 ESC.

The forward monitoring programme is another high priority area that LLW Repository Ltd will need to develop in the short-term, so that it continues to meet the requirements of the GRA. As discussed in section 4.15, we expect the company to present a comprehensive long-term monitoring and sampling strategy that is capable of supporting the ESC. We have asked LLW Repository Ltd to make sure that it uses the programme appropriately to reduce uncertainties in the ESC. We have raised a number of FIs to outline our requirements.

As a high priority in the short-term we expect LLW Repository Ltd to:

- Update and develop the non-radioactive contaminant hydrogeological risk assessment as discussed in sections 3.6 and 4.11.
- Review probabilistic and deterministic groundwater pathway assessment models and their use in radiological capacity calculations, along with the need for any development work on probabilistic assessment models to determine the most appropriate way of defining radiological capacity for this pathway.
- Review past disposals of discrete items and particles where available information allows, identifying the possible implications and any necessary action required. This review should consider the assessments that were updated following the 2011 ESC that take account of waste heterogeneity.

Over the longer term we expect LLW Repository Ltd to develop a better way of managing and reducing uncertainties. We also expect the company to develop a better understanding of the evolution of the coastline adjacent to the repository and conceptualisation of the erosion of the waste over the long-term.

We will agree with LLW Repository Ltd when and how it intends to address the FIs and we will track progress made to resolve them. We expect the company to demonstrate that it has a mechanism in place to take account of our recommendations. If it fails to address these recommendations, this could bring into question the adequacy of any future ESC.

LLW Repository Ltd prepared annual summaries of its research and development programme in the period leading up to 2011 under Schedule 9 Requirement 4 of its current environmental permit. However, it did not present a forward looking research programme in the 2011 ESC. We consider that specific research is needed to reduce uncertainties in some areas, for example regarding the performance of engineered materials and the evolution of the vault waste form over time. We require LLW Repository Ltd to include such research in its wider forward programme.

We are aware that LLW Repository Ltd is developing a substantial programme of work that will address many of the FIs and recommendations we have raised. For example, at the time of writing the company was preparing a review of available monitoring approaches and techniques that could be used for long-term monitoring at the LLWR, drawing on practice and plans at sites in the UK and overseas. We anticipate that the output from this work will include proposals for laboratory and/or in-situ experiments and/or monitoring of the engineered system. Similarly, the company is currently developing its near field work programme for the period leading up to the next ESC. This work will build on the company's thinking at the time of the 2011 ESC, the results of subsequent near field studies, our review comments and comments from the peer review group. We expect the programme to include targeted research.

We expect LLW Repository Ltd to bring together the programmes of work discussed above into an integrated forward programme that is linked to uncertainties in the 2011 ESC. We will work with the company to make sure that this integrated programme meets our regulatory expectations, with the aim of LLW Repository Ltd ensuring continued improvement to its ESC.

6. Conclusions

LLW Repository Ltd submitted an environmental safety case (ESC) for the Low Level Waste Repository (LLWR) to the Environment Agency on 1 May 2011 (the 2011 ESC) in response to Schedule 9 Requirement 6 of the current LLWR environmental permit. The 2011 ESC covers the period up to withdrawal of control and thereafter. We carried out a detailed technical review of this ESC to determine whether it adequately meets Requirement 6. We also considered whether it meets all the requirements of the guidance on requirements for the authorisation of near-surface disposal facilities for solid radioactive waste (the GRA). In our review, we have considered the ESC as submitted in 2011 as well as other technical work carried out in the period leading up to LLW Repository Ltd's permit application that we received on 28 October 2013. The outcomes of this review form a major input to our regulatory decision whether to permit the LLWR for further disposal of radioactive waste.

The 2011 ESC submission is of good quality and has generally proved clear and concise. LLW Repository Ltd has directly addressed the GRA requirements with evidence and further supporting evidence has been readily traced. The level of detail in the 2011 ESC is proportionate to the hazard associated with the LLWR. However, during our review we had to request information not included in the original submission and raise a number of issue resolution forms to obtain further information to support our review. With reference to this additional information, the 2011 ESC was sufficient and comprehensive enough to allow us to complete our review.

We consider that LLW Repository Ltd has demonstrated that it has adequately met all the principles and requirements of the GRA at this stage of development of the repository. This is consistent with achieving an appropriate level of environmental safety at the LLWR now and in the future. Appropriate resources and management systems are in place to allow LLW Repository Ltd to continue to operate the site in accordance with the ESC and our requirements.

We expect LLW Repository Ltd to continue to develop its ESC as a live case, with ongoing annual, periodic and major reviews. We expect a forward programme of work to be developed and maintained. We will work with LLW Repository Ltd to make sure that this forward programme of work meets our regulatory expectations with the aim of ensuring continued improvement to the ESC and continued compliance with the requirements of the GRA. In support of this, we raised a number of forward issues on important areas where we see scope for continued improvement in the ESC and its implementation. We will monitor progress against these forward issues and will require further improvements to be made, so that the ESC continues to meet our expectations. We have also made recommendations on areas where we see scope for possible improvement or development. These forward issues and recommendations should only be one input into the forward programme of work, which should be informed by LLW Repository Ltd’s wider understanding of the site, the 2011 ESC and monitoring data, amongst other inputs.

Overall, 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. We are satisfied that the 2011 ESC and supporting documents demonstrate that further disposal of radioactive waste at the facility will be safe for people and the environment both now and in the long term. Based on this evidence we will describe our proposed decision on permitting further radioactive waste disposal at the LLWR within a draft decision document, supported by a draft permit. We will consult on this draft decision before reaching a final decision and varying the environmental permit for the LLWR. Through the environmental permit we will continue to regulate the LLWR to make sure that it remains safe for people and the environment and that the ESC continues to support any activities carried out.

7. References

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List of abbreviations

AD	Anno Domini
ALARA	As low as reasonably achievable
BAT	Best available techniques
BNFL	British Nuclear Fuels Limited
BNGSL	British Nuclear Group Sellafield Limited
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EDA	Extended disposal area
EDTA	Ethylene diamine tetra-acetic acid
EPR10	Environmental Permitting (England and Wales) Regulations 2010, as amended
ERICA	Environmental Risks from Ionising Radiation in the Environment: Assessment and Management
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
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IAF	Issue assessment form
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
LLWRAS	LLW Repository Assessment Standards
LLWTS	Low level waste tracking system
mSv	Millisievert
NDA	Nuclear Decommissioning Authority
NNL	National Nuclear Laboratory
NRPB	National Radiological Protection Board, now part of PHE
NWAT	Nuclear Waste Assessment Team

OESC	Operational environmental safety case
OHSAS	Occupational Health and Safety Advisory Service (standard)
PCSC	Post-closure safety case
PHE	Public Health England
PIER	Projected Inventory Evaluation Routine (model)
PoA	Period of authorisation
PWR	Pressurised water reactor
RI	Regulatory issue
RO	Regulatory observation
RSA 93	Radioactive Substances Act 1993 (as amended)
SI	International System of Units
SLC	Site licence company
Sv	Sievert
TQ	Technical query
UKAEA	United Kingdom Atomic Energy Authority
UKNWM	United Kingdom Nuclear Waste Management Ltd
WAC	Waste acceptance criteria
µSv	Microsievert
µGy	Microgray

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 radioactive-decay processes, the number of disintegrations per second, or the number of unstable atomic nuclei that decay per second in a given sample.
Alkali	A substance with a relatively low concentration of hydrogen ions and a pH greater than 7.
Alpha particle	A positively charged particle consisting of two protons and two neutrons, emitted in radioactive decay or nuclear fission; the nucleus of a helium atom.
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.
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.
Calculation case	A calculation case is a specified combination of events, circumstances, conditions or their evolution, including specification of model boundary conditions and data, which represents a particular realisation of the disposal system, its evolutions and radionuclide or contaminant release, migration and exposures. A large number of cases may be required to adequately explore aspects of, or uncertainties within, a scenario. Where the meaning is clear the abbreviated term, 'case', is used.
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.
Chelating agents	A chelating agent is a substance whose molecules can form several bonds to a single metal ion.
Colloid	A small particle or molecule dispersed in a second medium that has at least one dimension between approximately 1 nm and 1 µm.
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.

Complexation	Is the process by which a ligand (complexant) and metal bind together to form a new chemical species.
Computer code (or code)	A software implementation of a numerical model that uses a computer processor to solve equations.
Conceptual model	A set of qualitative assumptions used to describe a system, or part of a system, in the real world.
Conservative (of assumptions and data)	Cautious in the sense that impacts would be overestimated.
Critical group	A group of members of the public that is reasonably homogeneous with respect to its exposure for a given radiation source, such as a near-surface disposal facility, and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) from that source.
Decay chain	A sequence of radioactive decay processes, in which the decay of one element creates a new element that may itself be radioactive. The chain ends when stable atoms are formed.
Deterministic	A deterministic analysis is one in which each input parameter is assigned a single numerical value, leading to a single value for the result.
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.
Discretisation	Is the process of breaking down a large model into discrete sections or compartments that are individually represented within a model.
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 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).
Dose guidance level (for human intrusion)	In the context of near-surface disposal facilities, the dose standard against which the radiological consequences of human intrusion are assessed. It indicates the standard of environmental safety expected but does not suggest that there is an absolute requirement for this level to be met.
Dose rates	The radiation dose (dosage) absorbed per unit of time.

Effective dose	The sum of the equivalent doses from internal and external radiation in all tissue and organs of the body, having been weighted by their tissue weighting factors. The unit of effective dose is the sievert (Sv).
Effluent	An out flowing of water from a natural body of water, or from a man-made structure. Effluent in the man-made sense is generally considered to be pollution, such as the outflow from a sewage treatment facility or the wastewater discharge from industrial facilities.
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 in order to reduce 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.
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.
Exposure pathway	An exposure pathway refers to the way a person can come into contact with a hazardous substance. There are three basic exposure pathways: inhalation, ingestion, or direct

	contact. A person can also receive dose from radioactive substances via external irradiation.
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.
Fissile	Fissile material is material capable of sustaining a nuclear fission chain reaction. By definition, fissile material can sustain a chain reaction with neutrons of any energy (as opposed to 'fissionable' material requiring high-energy neutrons).
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.
Human intrusion	Any human action that accesses the waste or that damages a barrier providing an environmental safety function after the period of authorisation.
Infiltration	The process in which a fluid passes into the pores of a solid.
Ingrowth	Additional radioactivity produced as a result of radioactive decay of parent radionuclides.
Inorganic	Not having the structure or characteristics of living organisms; not organic.
Inundation	The ephemeral or permanent covering of all or part of the repository by water. Inundation may occur without large scale disruption of the waste.
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.
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.
Operational environmental safety case	The 2002 ESC submitted by LLW Repository Ltd was split into two parts, the first being the operational environmental safety case, which addressed matters of environmental safety during the period of authorisation.
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.
Oxidation	A chemical reaction that involves the loss of electrons or an increase in the oxidation state of a molecule, atom or ion.
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.
Peer review	A formally documented examination of a technical programme or specific aspect of work by a suitably qualified expert or group of experts who have not been directly involved in the programme or aspect of work.
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.
Quaternary	The latest period of time in the stratigraphic column, 0 to 2 million years before present, typically represented by local accumulation of glacial (Pleistocene) and post-glacial (Holocene) deposits.
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.
Radionuclide fingerprint	A radionuclide fingerprint is a measurement or estimate of the relative proportions of radionuclides present on or in an article, substance or waste, and is used to estimate the amounts of radionuclides in other similar wastes.
Receptor	Something that could be adversely affected by a contaminant, such as people, an ecological system, property or water body.
Reference case	The baseline set of assumptions about the disposal facility and its evolution with time that is used in the calculations of dose and risk.
Reference design	The engineering design arrived at through optimisation studies within the 2011 ESC. It is used as the basis for detailed assessments of facility performance and radiological and non-radiological impacts within the 2011 ESC.
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).
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 and human-induced, events and processes.
Sievert (Sv)	The International System of Units (SI) unit of effective dose, obtained by weighting the equivalent dose in each tissue in the body with ICRP-recommended tissue-weighting factors, and summing over all tissues. Because the Sievert is a large unit, effective dose is commonly expressed in milli-Sieverts (mSv) – that is, one thousandth of one Sievert, and micro-Sievert (μSv) – that is, one thousandth of one milli-Sievert.
Site development plan (SDP)	Sets out proposals and assumptions about 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.
Site Licence Company	The legal entity (LLW Repository Ltd) that operates the LLWR on behalf of the Nuclear Decommissioning Authority (NDA).
Source term	Description of the characteristics of the waste inventory (for example radioactivity, chemical hazard and volume) used as a basis in assessments of environmental impacts.
Specific activity	Radioactivity per unit mass of a waste.
Sum of fractions	An approach to setting limits on the total quantities and specific activity of radionuclides that may be disposed of at a radioactive waste repository. The approach is based on derivation of values of radiological capacity for each assessment case and for each radionuclide. A key characteristic of the approach is that it addresses the additive contributions of different radionuclides to overall impacts.
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 was tumble tipped.
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.
Variant cases	Alternative calculation cases that are defined to investigate the effect of uncertainty in FEPs on the risk and dose calculations.
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 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 from 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.
What-if scenario	A scenario put forward to explore the consequences of a defined set of assumptions that have a low likelihood of occurring.

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