



Review of LLW Repository Ltd's 2011 environmental safety case: Issue assessment forms

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. As part of its current environmental permit LLW Repository Ltd had to submit an Environmental Safety Case (ESC) for the Low Level Waste Repository (LLWR) in west Cumbria to the Environment Agency by 1 May 2011 (the 2011 ESC).

This report covers our review of whether the 2011 ESC adequately takes into account the recommendations that we made during our review of the previous LLWR ESCs; the 2002 Operational Environmental Safety Case and Post-Closure Safety Case. The outputs from this report are integrated with our review of the 2011 ESC.

We adopted a formal process for tracking identified issues in our review of the 2002 ESCs. We defined an 'issue' as something that is or is likely to be:

- significant to the quantitative or qualitative assessment of radiological impact or other safety measures, or
- important in demonstrating that the operator understands the disposal system, or
- important in demonstrating that the operator has control over the environmental safety of the facility

We documented these issues on Issue Assessment Forms. We raised 136 Issue Assessment Forms, which detailed a total of 299 recommendations to the LLWR operator, which was then British Nuclear Fuels Ltd.

We reviewed the response of the current LLWR operator, LLW Repository Ltd, to each of the Issue Assessment Form recommendations and the company's treatment of the issues in the 2011 ESC. In our review, we took into account a number of significant changes to the LLWR ESC in the period between 2002 and 2011. Of particular relevance are:

- The understanding that the LLWR is almost certain to be destroyed by coastal erosion, with erosion commencing within a few 100 to a few 1000 years from now. Thus the 2011 ESC focuses on a much shorter timeframe than the 2002 Post-Closure Safety Case.
- Significant effort has been directed at understanding past disposals to the trenches in terms of activity, waste form, heterogeneity and location of key disposals.
- The engineering design of the facility, including future vaults and the closure engineering system, has been subject to extensive optimisation, resulting in updated designs.
- Increased computer power has improved the sophistication of the models used to project the behaviour of radionuclides in the disposal facility and the wider environment and estimate doses and risks.
- The risks and doses projected in the 2011 ESC safety assessment are lower than those projected in the 2002 ESCs and are considered acceptable.

Because of these changes, some of the issues considered to be outstanding at the end of our review of the 2002 ESCs, as documented in the Issue Assessment Forms, are no longer relevant. However, even in areas where understanding has significantly moved on, we identified many general points of relevance to the 2011 ESC. Thus we classified only 27 of a total of 299 Issue Assessment Form recommendations as 'not relevant'. We consider that LLW Repository Ltd satisfactorily addressed the majority of the remaining Issue Assessment Form recommendations in the 2011 ESC. However, 27 IAF recommendations were linked to similar issues that we raised in Issue Resolution Forms in our review of the 2011 ESC. LLW Repository Ltd subsequently addressed these issues to our satisfaction and we closed them.

We consider that recommendations made in some of the Issue Assessment Forms were not fully addressed in the 2011 ESC and could benefit from further work. None of these issues are significant enough to prevent the 2011 ESC from meeting our guidance on requirements for the authorisation of near-surface disposal facilities for solid radioactive waste. However, we expect

LLW Repository Ltd to develop and maintain a forward programme of work to ensure continued improvement to the ESC and continued compliance with our requirements. We have therefore closed all the Issue Assessment Forms and have raised actions on outstanding issues. We include outstanding issues from 47 of the Issue Assessment Forms in a number of Forward Issues, which cover 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. In addition, we have made a number of new recommendations to LLW Repository Ltd on areas where we see scope for potential improvement or development. We will work with LLW Repository Ltd to ensure that its forward programme of work meets our regulatory expectations.

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1. Introduction

1.1. Introduction

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

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

The aims of the review were:

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

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

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

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

1.2. The 2011 ESC submission

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

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

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

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

<http://llwrsite.com/national-repository/key-activities/esc/esc-documentation/>

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

1.3. The review process

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

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

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

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

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

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

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

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

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

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

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

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

1.4. ESC review deliverables

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

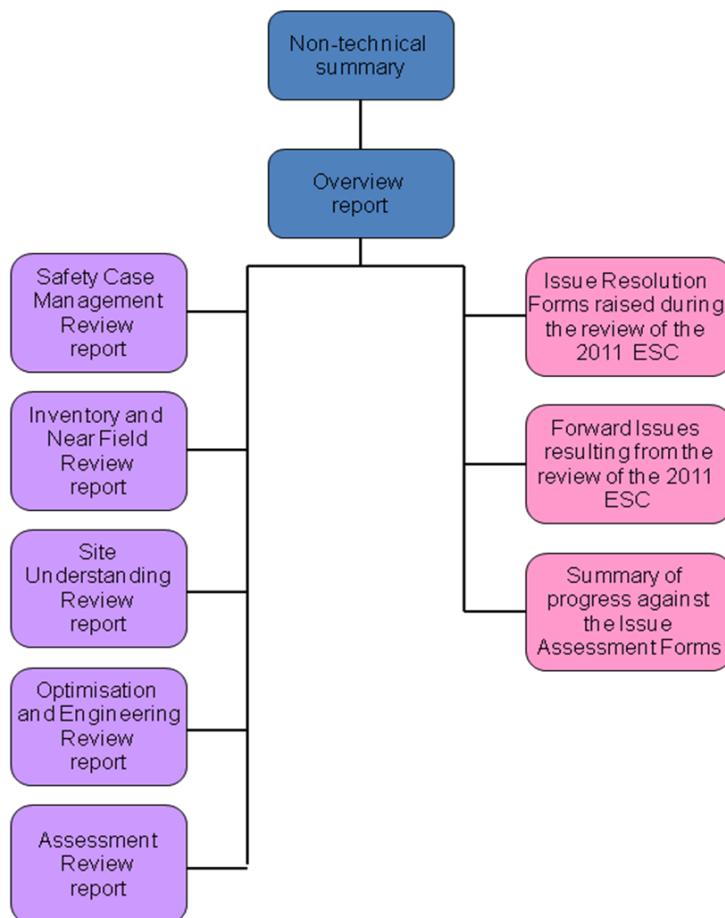


Figure 1 The Environment Agency review of the 2011 ESC: Document structure

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

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

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

We documented concerns from our review of the previous LLWR Operational Environmental and Post-Closure Safety Cases (the 2002 ESCs; British Nuclear Fuels Ltd (BNFL) 2002a,b) on Issue

Assessment Forms (IAFs), which are similar to the IRFs. We report our review of LLW Repository Ltd's progress in addressing actions raised in the IAFs in this report. Further information on the issue assessment process is provided in Section 2.1. Any actions that we consider have not been fully addressed in the 2011 ESC are taken forward in the FIs or recommendations.

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

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

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

2. Process

2.1. Issue assessment process

A summary of our review of the 2002 LLWR ESCs is provided in Environment Agency (2005a). During the review, we adopted a formal process for tracking identified issues. This was termed the issue assessment process.

An 'issue' in this context may be considered to be something that is or is likely to be:

- significant to the quantitative or qualitative assessment of radiological impact or other safety measures, or
- important in demonstrating that the operator understands the disposal system, or
- important in demonstrating that the operator has control over the environmental safety of the facility

Issues identified were documented on an IAF, which took the form of a statement of the issue, a description of our understanding of the position taken by the then site operator, BNFL, and our evaluation of that position. This form was subsequently used to record BNFL's response to the issue and our evaluation of whether BNFL's safety cases met our requirements in relation to that issue and, where appropriate, relevant recommendations for BNFL and/or the Environment Agency. These conclusions were a major input to our decisions in relation to the authorisation issued in 2006.

A series of IAFs was compiled by each of 12 technical review groups set up to review the 2002 ESCs, which cover the following areas:

- Core Group
- Site Development and Engineering
- Cap
- Near Field
- Geosphere
- Biosphere
- Gas
- Disruptive Events
- Assessment Codes
- Parameters
- Operational Environmental Safety Case (OESC)
- Radiological Capacity

In total we raised 136 IAFs, which detailed 299 recommendations to BNFL.

In the review, we assigned each issue to one of five categories:

- Review criterion (for example the IAF recommendation or GRA requirement) **not significant** to the ESC.
- Review criterion **failed**. The submission did not address the criterion or did so in a way that was clearly inadequate.
- Review criterion **partially met** but reservations remain. The criterion was addressed but not fully met – the reservations that prevented it being fully met were sufficiently serious that, if not corrected within an appropriate timescale, they would lead to a failure on that criterion.
- Review criterion **partially met but observations remain**. The criterion was addressed but not fully met – the observations that prevented it being fully met should be addressed in due course but were not sufficiently serious that they would lead to a failure on that criterion.
- Review criterion **met**.

LLW Repository Ltd issued several summaries of progress against the IAFs during the programme of work developed to address the issues associated with the 2002 ESCs and the resulting authorisation (Paulley and Lean 2006; Grimwood 2007; Lean 2007). A formal re-assessment of the IAFs and corresponding technical recommendations, and how they have been addressed, or were intended to be addressed in the programme of work leading to the 2011 ESC, was issued in 2009 (Sumerling et al. 2009).

2.2. Assessment of the treatment of issues in the 2011 ESC

Based on consideration of LLW Repository Ltd's response detailed in Sumerling et al. (2009) and taking into account the way in which the issues have been addressed in the 2011 ESC, we have reviewed the status of the IAFs. We have designated each issue as one of the following:

- **Issue not relevant:** An issue raised in the past may no longer be relevant in the context of the 2011 ESC and the ongoing operation and management of the LLWR.
- **Issue closed:** An issue is considered closed when we are satisfied that it has been resolved. This is not an absolute guarantee that no questions on the issue will be raised by us subsequently, particularly if there are changes in the context in which the issue arises. However, it does indicate that we would not expect the issue to need revisiting.
- **Issue closed with recommendation(s):** We consider that the issue has been treated adequately for the purposes of the 2011 ESC. However, we believe that improvements to the treatment of the issue could be enacted in future iterations of the ESC. Specific recommendations for LLW Repository Ltd to consider are provided.
- **Issue subsumed into Issue Resolution Form (IRF):** An issue raised in the past or in a specific context may be superseded, if ongoing developments render it no longer significant, or appropriate to subsume into another issue. For practical purposes the original issue will be closed, but we retain the distinction for the purposes of maintaining a clear audit trail. A link to the relevant IRF(s) is provided, and a summary of whether we are in agreement with LLW Repository Ltd's response to the IRF(s). All IRFs have been closed to our satisfaction or linked to a Forward Issue (FI).
- **Issue carried through to a forward issue (FI):** We consider that information provided in the 2011 ESC and the LLW Repository Ltd summary of progress against the IAFs falls short of expectations, raises new questions, or there remains continued scope for improvement. However, we consider that this issue does not in itself imply the ESC for the LLWR is not adequate overall. The issue will be carried directly through to a FI and a summary of the proposed closure mechanisms will be provided as part of the FI.

Throughout our review of the IAFs, we make a number of specific recommendations to LLW Repository Ltd. These recommendations are numbered in this document and are linked to our technical review reports, as follows:

- Recommendation SCMxx: Safety Case Management (Environment Agency 2015b)
- Recommendation INFxx: Inventory and Near Field (Environment Agency 2015c)
- Recommendation SUExx: Site Understanding (Environment Agency 2015d)
- Recommendation O&Exx: Optimisation and Engineering (Environment Agency 2015e)
- Recommendation ASSxx: Assessments (Environment Agency 2015f)

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.

3. Progress against IAFs

3.1. Introduction

The 2011 ESC does not specifically reference the issues raised from the 2002 ESCs. We have assessed the outstanding IAF issues (recommendations) against the summary provided by Sumerling et al. (2009) and information provided in the 2011 ESC, together with other documents and further information provided up to the date of LLW Repository Ltd's application to vary the LLWR environmental permit in October 2013 (LLW Repository Ltd 2013c,d).

A summary of the status of the IAF recommendations at the end of our review of the 2011 ESC is provided in Table 1. Further detail of our assessment of the IAFs is provided in Appendices 1 to 12, each appendix addressing one of the technical review group areas.

Table 1 Summary of assessment of the status of the IAF recommendations at the end of the review of the 2011 ESC

Technical review group	Number of IAF recommendations considered to be:					
	Not relevant	Closed	Closed with recommendation	Closed - subsumed into IRF	Carried through to FI	Total
Core	2	18	5	5	0	30
Site development and engineering	4	8	1	0	14	27
Cap	1	2	0	0	6	9
Near field	3	31	6	5	9	54
Geosphere	6	28	21	1	6	62
Biosphere	1	19	9	3	1	33
Gas	1	11	1	1	0	14
Disruptive events	1	7	0	5	3	16
Assessment codes	3	0	1	0	0	4
Parameters	4	8	1	4	0	17
OESC	1	17	3	3	8	32
Radiological capacity	0	1	0	0	0	1
Total	27	150	48	27	47	299

The majority of recommendations raised in the IAFs remain relevant to the 2011 ESC. We have identified a number of areas that would benefit from further work; however, none are significant enough to prevent the 2011 ESC from meeting the requirements of the GRA (Environment Agency et al. 2009). Therefore, we have closed the remaining IAFs. Twenty seven IAF recommendations may be linked to issues raised in our review of the 2011 ESC, which were subsequently addressed to our satisfaction. Forty eight IAF recommendations are associated with new recommendations

for future improvements to the ESC (some recommendations for future improvements may be associated with more than one IAF). Forty seven of the IAF recommendations are linked to FIs that should be addressed by LLW Repository Ltd in the period leading up to the submission of the next ESC. The majority of these FIs are related to the engineering forward programme.

A summary of our assessment of the progress made against the IAFs in each of the technical review areas is provided in the following sections. Where appropriate, reference is made to IAFs within individual technical review reports (Environment Agency 2015b to 2015f).

3.2. Core IAFs

The 2002 Post Closure Safety Case (PCSC) Core Review Group reviewed the treatment of selected high level topics in the PCSC, such as adherence to the principles and requirements of the 1997 GRA (Environment Agency et al. 1997). The Core Review Group also had oversight of the other review groups (excluding the OESC Review Group).

The Core Review Group considered that the 2002 Post Closure Radiological Safety Assessment (PCRSA) had been developed in line with many of the 1997 GRA requirements, and that it 'represented a more thorough evaluation of the potential environmental impacts associated with the Drigg disposal facility than was provided by previous Drigg assessments' (Galson Sciences Ltd and Environment Agency 2004a). However, the Review Group concluded that the 2002 PCSC did not make a convincing case for continued disposal at the LLWR because:

- Calculated risks to members of the public in the future exceeded the 1997 GRA risk target of one in a million per year (now termed the risk guidance level) by a significant margin and for several exposure pathways, predominantly owing to long-lived waste disposed of in the trenches.
- The site might be destroyed by coastal erosion in the relatively near future (then considered between 500 to 5,000 years).
- The 2002 PCSC included insufficient consideration of optimisation and intervention / risk management.
- The description of the forward work programme did not provide sufficient confidence that appropriate risk management work will be conducted.

The 2011 ESC presented an entirely new safety assessment. Risks and doses calculated for the post-closure period are below the relevant guidance levels for all but the most extreme variant cases. One of the major changes was the current understanding that the LLWR is likely to be destroyed by coastal erosion, with erosion commencing on a timescale of several 100 to several 1000 years. The peak risks calculated in the 2002 PCRSA were associated with exposure to uranium-234 (U-234) and thorium-230 (Th-230) 10s of 1000s of years in the future. Because the 2011 ESC projects that the LLWR will only remain intact over extended periods if current sea level trends are subject to reversal, this scenario is considered extremely unlikely. LLW Repository Ltd has also carried out a number of optimisation studies since 2002, resulting in an updated repository engineering design. Thus many of the issues raised by the Core Review Group have been adequately addressed in the 2011 ESC and subsequent studies leading up to the environmental permit variation application issued to us by LLW Repository Ltd in October 2013.

LLW Repository Ltd treated uncertainty in the 2011 safety assessment through use of a range of different scenarios for the main environmental pathways. The company used variant cases to explore parameter uncertainty and (for the groundwater pathway) conceptual model uncertainty. A probabilistic calculation was carried out for the groundwater pathway well scenario. Although this provided an improvement over the 2002 PCSC, addressing much of COR_020, we consider that all key uncertainties have not been systematically identified and assessed. We raised this issue in IRF ESC-RO-ASO-004. Although LLW Repository Ltd provided us with sufficient further information to allow us to close this IRF, we ask the company to further develop its system for the management of uncertainties in FI ESC-FI-008.

Our review of the Core Review Group IAFs has also resulted in a number of recommendations to LLW Repository Ltd that should be taken forward in future updates of the ESC:

- LLW Repository Ltd should keep under review developments in observation and modelling of climate change and the evolution of the local coastline, and make sure that the ESC continues to reflect the best evidence about the likely fate of the site (COR_001 and Recommendations SUE39 and SUE40).
- LLW Repository Ltd needs to review records management post-delivery of the ESC (COR_010 and Recommendation SCM16).
- Information on the interactions between computer models and the transfer of model output between different models should be presented better in future ESCs; good practice would include provision of an assessment model flowchart or similar (COR_018.1 and Recommendation ASS27).
- Future ESC submissions should aim, as far as possible, to include all relevant information to 'make the case' with a reduced need for us to request further information (COR_024.2 and Recommendation SCM5).
- Regular liaison between LLW Repository Ltd and the Environment Agency has worked well during the development of the ESC and should be continued (COR_024.4 and Recommendation SCM1).

3.3. Site development and engineering IAFs

The 2002 PCSC presented a design concept for the repository that is broadly similar to that presented in the 2011 ESC. Since 2002, the closure engineering design has been subject to extensive optimisation, with the main change being the move from a vertical drainage system to a horizontal basal drainage layer. The basal drainage system is designed to disperse over-topped leachate from the future vaults into a deeper groundwater environment to avoid leachate reaching the near-surface environment. The recommendations made by the Site Development and Engineering (SDE) Review Group (Galson Sciences Ltd and Environment Agency 2004b) reflect a superseded repository design and engineering concept. In our review of the IAFs in this area, we have only considered those that remain applicable and relevant.

The issues raised in the SDE review relating to the presentation of the engineering design have many similarities to the issues we raised during our review of the 2011 ESC. The 2002 PCSC incorporated a more comprehensive and extensive assessment of engineering performance. We recognised in our review of the 2002 PCSC that this assessment may have been too complex, and that the outcome was the identification of 2 main performance differentiators (increased barrier permeability and reduced flow in granular drainage components). As documented in the 2011 ESC, LLW Repository Ltd now takes the view that, due to the likely coastal disruption, the engineering systems will need to function over a shorter period. The 2011 ESC engineering design and its subsequent assessment was carried out using a single conceptual design and a set of elicited performance assumptions. A discrete engineering performance assessment (EPA) was not carried out to support the 2011 ESC, although work has been undertaken on the performance of barriers, cap settlement and hydrogeological modelling. However, as documented in FI ESC-FI-026, we have asked LLW Repository Ltd to further consider the adoption of an EPA framework in future ESCs.

We also note that the 2011 ESC assessment assumes the loss of the hydraulic barrier functionality of the capping system after a period of several 100 years; this is a conservative assumption and reduces the need to assess a range of cap failure mechanisms. Although, we consider the capping system degradation assumptions presented in the 2011 ESC appropriate, we identified the need to assess a wider range of discrete failure mechanisms. Cap behaviour issues are discussed further in the following section.

The 2002 PCSC assumed that the engineering design will be further optimised before the start of construction. The 2011 ESC engineering design remains at a relatively conceptual design stage with the design incorporating contemporary materials and design practice to support the design principle. To implement the 2011 ESC engineering design, both LLW Repository Ltd and we expect the engineering design to undergo further optimisation and detailed assessment to reflect increased material performance data prior to construction.

The 2002 PCSC made commitments to carry out field trials for the individual functional capping layers, with the outcome from these trials significantly improving confidence in the assumed performance of the cap. These trials have not been instigated since 2002 and do not form part of the 2011 ESC or associated forward programme. Since 2002, the design has evolved without field trial information and will be developed further to a more detailed design. We consider it is essential that LLW Repository Ltd carries out relevant field trials as the design for the first restoration strip is developed. We expect relevant engineering performance monitoring to be completed through LLW Repository Ltd's forward engineering programme (addressed within ESC-FI-026).

We do not consider that LLW Repository Ltd has fully addressed a number of the IAFs in the 2011 ESC. This is unsurprising given that the development of the detailed engineering design is an ongoing task that will continue up to and even during the construction phases. Outstanding issues are captured within our FIs relating to the engineering forward programme (ESC-FI-001, ESC-FI-023, ESC-FI-024, ESC-FI-026 and ESC-FI-027). These FIs set out our expectations for work to further optimise the engineering design and to assess the performance of the individual engineering components in the run up to and during construction.

Issues not closed from the 2002 PCSC review that are taken forward in these FIs include:

- Further reassurance and design validation for the components of the engineered system, in particular relating to a reduction in the reliance on elicited performance data in favour of data based on empirical evidence wherever possible and beneficial (SDE_002.2, SDE_004.1, SDE_006.1 and SDE_007.3)
- improved understanding of long-term performance (SDE_002.1, SDE_004.2, SDE_007.4 and SDE_007.5)
- improved understanding of uncertainty and failure/performance change in the behaviour of the engineered system (SDE_003.1; SDE_003.2, SDE_005.1 and SDE_006.2)
- demonstration of as-built performance in line with design expectations and equivalency to the ESC performance assumptions and assessment of design evolution (SDE_004.4 and SDE_007.2)

We consider that LLW Repository Ltd's forward engineering programme is capable of addressing these outstanding issues (Shaw 2013). We will review progress against these issues during the design justification process as part of our routine regulatory interactions.

We note that references for the sources of information used in the data elicitation process supporting the 2011 ESC (as reported in Jackson et al. 2011) could have been more clearly presented and referenced. We raised similar concerns in our review of the 2002 PCSC (SDE_006.1). We ask LLW Repository Ltd to make improvements to the elicitation process, and its documentation, in ESC-FI-029.

Other relevant IAFs were addressed satisfactorily in the 2011 ESC. We have made 3 recommendations to LLW Repository Ltd as a result of our review of the SDE IAFs in the context of the 2011 ESC, in that we expect the company to improve its derivation of the non-radioactive component of the LLWR inventory, including the associated uncertainty (SDE_008.1 to SDE_008.5 and Recommendations INF10 to INF12).

3.4. Cap IAFs

The 2002 PCSC Cap Review Group assessed the overall methodology for developing conceptual models of cap behaviour and the assumptions used to model the cap performance (Galson Sciences Ltd and Environment Agency 2005a). A number of recommendations were made covering: cap infiltration and the EPA; representation of climate change; water balance modelling; implications on human intrusion; and gas transport and dose assessment.

The cap designs presented in both the 2002 PCSC and the 2011 ESC are similar, both comprising a single dome design¹. The conceptual designs of the layers within the final engineered cap have not changed significantly between the 2002 PCSC and the 2011 ESC.

As discussed above, the 2002 PCSC included a comprehensive EPA that assessed in detail the performance of, and interactions between, the components of the final engineered system, whilst the 2011 ESC adopted a simpler assessment approach, with cap performance based on elicited values (Jackson et al. 2011). There is little commonality between the two assessment approaches. Despite this, many aspects of the 2002 EPA may be of relevance to the 2011 ESC but have not been utilised fully within the 2011 ESC. LLW Repository Ltd indicates this is because of concerns over the validity of some of the information gained from the EPA and the evolution of the repository design concept.

The 2002 PCSC Cap Review Group identified a number of performance issues that are similar to ones we have identified in the 2011 ESC. Where applicable we have integrated recommendations into FIs derived from the 2011 ESC review.

Infiltration through the final cap is an important performance value for both the 2002 PCSC and the 2011 ESC, controlling the rate of generation of leachate and ultimately impacts via the groundwater pathway. We consider that the elicited cap infiltration values used in the 2011 ESC to provide a time dependant change in the rate of infiltration through the engineered capping system are reasonable for a capping system which has not been subject to physical disruption or settlement. However, we note that the detailed as-built performance expectations of the engineered capping system are yet to be determined. As part of a design substantiation review process, LLW Repository Ltd will need to assess whether (and where possible demonstrate) the cap performances presented can be achieved at the point of construction and throughout the life of the LLWR. This issue is taken forward through ESC-FI-001 and ESC-FI-027.

The 2002 PCSC considered the effects of cap failure and the review team raised a number of recommendations relating to the effect, and predicted rate, of bulk erosion of the final cap. These recommendations are of less relevance to the 2011 ESC, given that it is assumed that the LLWR will be disrupted by coastal erosion over a time frame of between 100s and 1000s of years. Therefore, the effects of bulk erosion of the capping materials will be less significant over the period it is expected to be required to serve its purpose. However, we do expect LLW Repository Ltd to assess the nature and extent of bulk erosion before site disruption.

Some of the potential implications of the nature and extent of settlement identified in the Vault 8 container investigation programme (Jefferies 2012; 2013; LLW Repository Ltd 2013a) were not investigated in the 2011 ESC. This is particularly of relevance given the observed degradation of containers in Vault 8 and significant settlement potential resulting from voidage in some containers. LLW Repository Ltd has acknowledged the need to conduct further investigations as part of a substantial engineering forward programme (Shaw 2013) into the likely effects of container degradation and settlement. The outcome of the programme will inform the design justification of the cap. This issue is carried through to ESC-FI-001.

LLW Repository Ltd assesses the performance of the interim trench cap on an annual basis in response to Requirement 7 of Schedule 9 of the current environmental permit (Environment Agency 2010). We asked LLW Repository Ltd to investigate a discrepancy between predicted and measured (via cap water balance studies) cap performance in IRF ESC-TQ-INF-018, which mirrors the recommendation in IAF CAP_005.2. LLW Repository's response to this IRF confirmed that the interim trench cap was not performing as well as assumed in the 2011 ESC. As a result of a subsequent best available techniques (BAT) study to assess options for improving the performance of the interim cap (Paulley et al. 2012), LLW Repository Ltd implemented a programme of repairs designed to reduce infiltration through the interim trench cap. During the repair work, further failures within the cap membrane were identified. At the time of writing LLW

¹ An alternative restoration cap design comprising two domes ('gull wing' design) was adopted in the period between the two safety cases, but this was rejected following engineering optimisation studies (see Paulley and Egan 2011).

Repository Ltd is reassessing its strategy for making the necessary improvements. We will continue to require LLW Repository Ltd to implement the BAT for the management of the interim trench cap before installation of the final cap. As outlined in ESC-FI-001, ESC-FI-025 and ESC-FI-027, we require this to be done before the construction of the final engineered cap. This issue is discussed further in Environment Agency (2015e).

We made no recommendations to LLW Repository Ltd as a result of our review of the cap IAFs in the context of the 2011 ESC. Because of the similarity of the issues raised in the IAFs and in 2011 ESC review we raised 6 engineering FIs that set out our requirements for the development of the engineering design (ESC-FI-001, ESC-FI-023, ESC-FI-024, ESC-FI-025, ESC-FI-026 and ESC-FI-027). These FIs include the CAP IAFs that were not satisfactorily addressed in 2011 ESC (CAP_001.1, CAP_001.2, CAP_002.1, CAP_002.2, CAP_003.2, CAP_004.1, CAP_005.1 and CAP_005.2).

Other relevant IAF recommendations were addressed satisfactorily in the 2011 ESC.

3.5. Near field IAFs

The 2002 PCSC Near Field Review Group considered the approach to the treatment of the near field as broadly acceptable (Galson Sciences Ltd and Environment Agency 2004c). However, a number of issues were raised that should be developed or clarified further in subsequent iterations of the ESC (that is the 2011 ESC).

In 2002, BNFL used the DRIngg Near field Kinetics (DRINK) model to underpin the conceptual understanding of the LLWR near field and provide the source term for the radiological assessment of the groundwater pathway. This model subsequently evolved into the Generalised Repository Model (GRM), which was used in the 2011 ESC. GRM has been used in a different way to DRINK in that it has been used to gain an understanding of the development of the facility over time, and how the chemical and physical conditions within the near field will change. Only carbon-14 (C-14) data directly output from GRM were used as inputs to the assessment calculations.

The Near Field Review Group had particular concerns regarding the supply of information and the documentation structure of the 2002 PCSC. The presentation of the near field information in the 2011 ESC is an improvement over the 2002 PCSC, but the audit trail for information in the Level 2 reports is poorly documented in places. In a number of instances we were not able to find all the information we needed in Level 3 documents and had to request further documents that were not included in the 2011 ESC as submitted. We also found it difficult to determine where information in early Level 3 documents had been superseded in later documents. LLW Repository Ltd should make sure that improvements in documenting the audit trail and provision of documents are carried through to the next ESC update (NRF_002 and NRF_003 and Recommendation SCM4).

We consider that the 2011 ESC near field assessment presents an improvement over the 2002 PCSC in many aspects. The majority of the near field IAFs were either adequately addressed or superseded by IRFs raised during our review of the 2011 ESC. However, we believe that issues raised in several IAFs were not sufficiently addressed within the 2011 ESC and these are taken forward via FIs:

- LLW Repository Ltd could improve the demonstration of understanding of the sensitivity of GRM (or an alternative near field model used in the future) to changes in the spatial discretisation of waste in the model. This is particularly important for C-14 as GRM output is used as direct input to the gas pathway assessment calculations (NRF_006.1). This is being taken forward via ESC-FI-016.
- LLW Repository Ltd should look to reduce key near field uncertainties, focusing on those uncertainties that are considered high and/or with the potential to affect the ESC as identified in the features, events and processes (FEP) and uncertainty tracking system (LLW Repository Ltd 2013b) (NRF_008.3 and ESC-FI-008).
- Although LLW Repository Ltd has demonstrated that elicitation studies can be used to generate long-term performance parameters for degraded barriers, we consider that the data could be further supported by research information (NRF_009.2). It is also important an effective linkage is maintained between the elicited performance values and the selected engineering materials

during the engineering forward programme (Shaw 2013) and design justification process. This is being taken forward via ESC-FI-026.

- Our review of the 2002 OESC identified the need for a quantitative assessment of the potential consequences of repository flooding (NRF_009.4). The assessment of the flood risk of the LLWR at a repository scale will be addressed as part of a planning application and is outside of the scope of our assessment of the 2011 ESC. Our review did cover the need to minimise and control vault leachate levels during the period of authorisation. We expect that, as part of the engineering forward programme, a full assessment of the flooding of the vaults is completed, particularly for Vault 8. This is being taken forward via ESC-FI-023 and will form part of a leachate management strategy.
- A watching brief should be maintained on developments in understanding the effects of colloids on radionuclide adsorption and transport in the environment. Periodic sampling for colloids should be carried in a proportionate manner out to further assess whether colloids do present a risk to the environment (NRF_010.1 and ESC-FI-015).
- A proportionate monitoring programme should be put in place to identify potential complexants in leachate and assess the potential implications on radionuclide migration (NRF_010.2 and ESC-FI-009).
- LLW Repository Ltd should make sure that the material types disposed of, in particular the relative quantities of grout and metal resulting from future changes in waste composition, are reviewed to make sure that the assumptions in the ESC remain valid. This might include, for example, an assessment of significant variations on the pH of the near field, and hence the partitioning of C-14 to the gas, solid and groundwater phases (NRF_014.2, NRF_016.3 and ESC-FI-014).

We have made 2 further recommendations that should be taken forward in future updates of the ESC. In summary, these cover the following issues:

- LLW Repository Ltd should make sure that the time steps used in future iterations of GRM (or alternative near field models) are optimised (NRF_006.2 and Recommendation INF15).
- Although we accept that microbial effects are of less significance to the 2011 ESC than to the 2002 PCSC, LLW Repository Ltd should maintain a watching brief on carbon energy sources for microbial species other than cellulosic materials that could affect the release of activity from the near field. This should include consideration of the potential for graphite to act as an energy source under anaerobic conditions and the potential effects of future treatments and future wasteforms on the near field environment (NRF_016.1 and Recommendation INF26).

3.6. Geosphere IAFs

The 2002 PCSC Geosphere Review Group felt that characterisation work had led to an improved knowledge of the site but that significant uncertainties remained (Galson Sciences Ltd and Environment Agency 2004d). The structure of documentation made it difficult to find pertinent information and supporting evidence, there was a lack of substantiation of assumptions and parameter values and treatment of conceptual and parameter uncertainties was considered inadequate. It was thus unclear how much confidence could be placed on the characterisation and modelling of the geosphere, and hence the reliability of the assessment results for the groundwater pathway.

During the development of the 2011 ESC, LLW Repository Ltd prepared revised conceptual models of the geology and hydrogeology in an iterative manner, drawing from recent site investigation work, for example the coastal geophysical survey (Halcrow 2010), and leading to an improved geoscientific understanding of the site. We note that 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. Some uncertainties remain, and we raised one related FI (ESC-FI-005) on the use of monitoring to reduce uncertainties.

Drawing from the updated geological and hydrogeological conceptualisations, LLW Repository Ltd developed an updated groundwater flow model in an iterative manner. The use of a detailed

groundwater flow model and supporting compartmental flow model represents good practice. The company investigated uncertainties in the conceptual model and parameterisation using deterministic variant cases along with a probabilistic assessment that considered variability in a limited number of parameters. However, we believe that the uncertainty assessment could be further improved by consideration of a fuller range of potential uncertainties (Recommendation ASS13).

We have made a number of further recommendations and raised FIs that should be taken forward in future iterations of site characterisation and modelling work. In summary, these cover the following issues:

- There should be an improved structure and clarity of reporting of future geological and hydrogeological characterisation and modelling work. We also expect those models being used within the ESC to be clearly identified and to have clear audit trails (GEO_005.1 and Recommendation SUE4).
- Further characterisation to reduce identified key uncertainties (for example dilution factors, heterogeneity, the geology and hydrogeology of the area between the LLWR and the coast and contaminant transport pathways), potentially including targeted site investigation and monitoring data, should be carried out and used to refine the conceptual models where practicable (GEO_001.4, GEO_003.4, GEO_018.2 and GEO_022.2, Recommendation SUE7 and ESC-FI-005).
- LLW Repository Ltd should continue to undertake a focused groundwater monitoring programme for tritium with the recognition that these data may provide important underpinning information for the groundwater flow and contaminant transport model and the radiological safety assessment (GEO_003.1 and ESC-FI-002).
- LLW Repository Ltd should periodically carry out proportionate analysis to determine if activity is associated with colloids (GEO_003.8, GEO_004.1 and GEO_004.2). This issue is taken forward via ESC-FI-015.
- LLW Repository Ltd should review the existing hydrogeochemical interpretation to determine the need for update, considering the implications of variability in the hydrogeochemical and mineralogical environment on contaminant sorption (GEO_003.8, GEO_003.9, GEO_015.1, GEO_015.2, GEO_015.3, GEO_015.4 and GEO_016.2 and Recommendation SUE31).
- The ESC would benefit from further work to determine retardation factors for the main contaminants that are appropriate to site conditions. LLW Repository Ltd should also review any future developments in the modelling of retardation (GEO_011.1, GEO_011.2, GEO_016.2 and GEO_016.3 and Recommendation SUE31).
- The ESC would benefit from further work to investigate the potential for incised channels in the main groundwater-bearing B3 unit to act as fast pathways (GEO_013.1 and Recommendation SUE8).
- LLW Repository Ltd should continue to review the importance of contaminant migration in the upper sandstone, considering the relative importance of fracture flow versus matrix flow in the upper sandstone and the effect of faults in the vicinity of the LLWR. If necessary, outcomes should be considered within the hydrogeological conceptualisation (GEO_009.2, GEO_23.1 and Recommendation SUE9).
- The implications of diffusion through engineered barriers should be investigated, or further substantiation provided, as to whether these diffusive fluxes are insignificant compared with advective fluxes (GEO_024.2 and Recommendation O&E12).
- LLW Repository Ltd should clearly substantiate its choice of parameters and data ranges used in the calibration of future hydrogeological models (GEO_002.3 and Recommendation SUE18).
- The implications of future climate change on a wider range of parameters, for example recharge and baseflow, should be considered within future assessments (GEO_017.1 and Recommendation SUE39).
- The effects of the construction of future vaults on contaminant migration should be considered, for example creation of preferential contaminant migration pathways (GEO_018.2, GEO_019.1, GEO_019.2 and Recommendation SUE11).

3.7. Biosphere IAFs

The 2002 PCSC Biosphere Review Group considered that the approach to the treatment of the biosphere, in particular that of modelling an evolving biosphere, was broadly appropriate (Galson Sciences Ltd and Environment Agency 2004e). However, the group had some reservations, in particular relating to the treatment of uncertainty and traceability of information.

The biosphere modelled in 2002 included consideration of a number of different 'system states', relating to future climate and landscape scenarios. Given that LLW Repository Ltd considers that it is almost certain that the LLWR will be destroyed by coastal erosion, with erosion commencing within a few 100 to a few 1000 years from now, the much shorter assessment timescale has meant that definition of alternative system states was not required. Thus a number of the comments from the 2002 PCSC review were not directly of relevance to the 2011 ESC. However, in most cases, we believe that the overall spirit of the recommendations, which reflect good practice, should be taken into account.

We note that the documentation of many features of the biosphere model such as potentially exposed group (PEG) descriptions, biosphere data and conceptualisations in the 2011 ESC has been carried out in a systematic and well-substantiated manner, thereby addressing a number of the IAF recommendations, in particular with reference to Thorne (2007; 2008; 2009) and Thorne et al. (2010). The treatment of uncertainty in the key FEPs has been clarified by using a FEP and uncertainty tracking system (LLW Repository Ltd 2013b). We welcome the audit of FEPs to the gas pathway calculations (Limer et al. 2011; Limer and Thorne 2011) as representing good practice, but would have liked to see a similar audit carried out for the groundwater, human intrusion and coastal erosion calculations (Recommendation ASS26).

The lack of an assessment of collective dose in the 2011 ESC means that recommendations relating to collective dose were not addressed (BIO_013.1). Outside of the IRF process, we asked LLW Repository Ltd to carry out an assessment of collective doses per year of LLWR operation for the UK, Europe and the World, expressed on an average per capita basis and integrated up to 500 years from now. The assessment, presented in Soetens and Jackson (2013), met our expectations (as discussed in Environment Agency 2015f).

We have raised 1 FI related to BIO_008.1 to ask LLW Repository Ltd to further investigate the long-term cap performance, evolution and failure of the cap, which should take into account the changing climate (ESC-FI-027). In addition, we have made a number of specific recommendations that should be taken forward in any future iteration of the safety assessment:

- The 2011 ESC groundwater pathway biosphere compartment model for the marine environment is virtually unchanged to that used in the 2002 PCSC. However, the coastal and marine biosphere used in the 2011 ESC coastal erosion assessment differed from that in the groundwater pathway assessment. LLW Repository Ltd satisfactorily justified these differences in response to IRF ESC-TQ-ASO-003. We recommend that future ESCs should have a greater consistency between the models for different pathways, including both physical representations of the biosphere and PEG habits, and that significant differences should be justified and implications on impacts identified (BIO_002.1 and BIO_006.2 and Recommendation ASS21).
- Further efforts should be made to improve understanding of background levels of radioactivity in and around the site (BIO_004.1 and Recommendation SUE51). [We note that, although LLW Repository Ltd committed to comparison between levels of radioactivity arising from the facility and those present naturally as a supporting safety argument (see Baker et al. 2008), this was not carried through to the 2011 ESC.]
- The ESC would benefit from further investigation of uncertainty associated with the geosphere-biosphere interface, in particular during cliff recession (BIO_005.1 and Recommendation ASS6).
- The ESC would benefit from greater clarity of documentation of PEG habits and values taken through to the assessment (BIO_006.1 and Recommendation ASS7).
- The ESC would be enhanced by collection of site-specific biosphere data that reflect conditions local to the LLWR (for example sorption data) (BIO_012.1 and Recommendation SUE54).

- The effect of variability and uncertainty in biosphere sorption coefficients should be considered in more detail for the near field and geosphere (BIO_012.2 and Recommendation ASS8).
- An audit of the calculations carried out for each pathway against the latest FEP list would represent good practice (BIO_001.3 and BIO_003.4 and Recommendation ASS26).

3.8. Gas IAFs

The 2002 PCSC Gas Review Group considered that the approach to the treatment of the gas pathway was broadly acceptable (Galson Sciences Ltd and Environment Agency 2004f). However, it highlighted a number of areas where further understanding and clarification was required. It was recommended that these should be addressed in the next iteration of the ESC (that is the 2011 ESC).

We consider that the majority of the issues raised during the review of the 2002 PCSC have been adequately addressed in the 2011 ESC. However, although we are satisfied that concerns relating to the gas vent model (GAS_002.1) have been addressed, we note that LLW Repository Ltd has not at present made a decision on whether the vent at the end of the period of authorisation will be left open or closed. Thus, although LLW Repository Ltd has addressed the vent issues via a 2-D model, we recommend that, once a final decision has been made, LLW Repository Ltd makes sure that the assumptions and conclusions within the ESC are still applicable. If not, this issue should be addressed in future iterations of the ESC (Recommendation ASS20).

3.9. Disruptive events IAFs

The 2002 PCSC assessment timescale was significantly longer than that considered in the 2011 ESC, as LLW Repository Ltd now considers it likely that the LLWR will be disrupted by coastal erosion, with erosion commencing within a few 100 to a few 1000 years from now. In 2002, an extended timescale of up to 100,000 years after present was assessed, and disruption by glaciation as well as by coastal erosion was considered. Thus a number of the disruptive events IAFs, for example those relating to long-term erosion of the cap, are no longer relevant.

Relatively high doses were calculated in the 2002 PCSC for human intrusion and coastal erosion, for example conditional risks were of the order of 10^{-4} y^{-1} for the latter in the very long-term. Because of this, the 2002 PCSC Disruptive Events Review Group recommended that further work on options for risk management was carried out (Galson Sciences Ltd and Environment Agency 2004g).

LLW Repository Ltd carried out major new human intrusion and coastal erosion assessments in the 2011 ESC (Hicks and Baldwin 2011; Towler et al. 2011), which include redefined PEGs and updated assessment models. These provide a major improvement on the 2002 PCSC. In addition, doses and risks calculated in 2011 are generally lower than those calculated in 2002 and are below the relevant guidance levels, thereby placing less emphasis on the need to assess options for risk management. The 2011 ESC makes the case for the disposal facility to be closed without the need for selective retrieval of waste (Paulley and Egan 2011).

A number of the issues raised in 2002 were identified during our review of the 2011 ESC as requiring further attention. Our main concern related to the breadth of scope of the calculation cases, in that they do not take into account all potential exposures. We requested further assessment to take account of waste heterogeneity for both the human intrusion and coastal erosion scenarios, and including illicit material recovery and exposure to radioactive sources and discrete items (raised in IRFs ESC-RI-ASO-010, ESC-RI-ASO-011 and ESC-RI-ASO-013). LLW Repository Ltd addressed these issues to our satisfaction and these IRFs are now closed. However, we have asked LLW Repository Ltd to present information on the distribution of key radionuclides and key materials for disposals to the vaults in future versions of the ESC, where benefits of doing this are identified, in ESC-FI-010. We have also asked the company to consider past disposals of discrete items, assess the possible implications and identify any resulting action required in advance of emplacement of the final cap in ESC-FI-013.

We also requested further work on risk management in the light of relatively high doses and risks from non-human biotic intrusion calculated in the 2002 PCSC (DIS_005.1). We raised a FI asking

LLW Repository Ltd to substantiate functionality claims within the engineered cap design, which includes the performance of a cobble layer to prevent bio-intrusion (ESC-FI-027). The outcome of this FI will clarify the likelihood and consequences of impacts associated with non-human biotic intrusion into the engineered cap.

3.10. Assessment codes IAFs

The 2002 PCSC included a series of reports documenting descriptions of, and substantiations for, models used in near field, geosphere and biosphere assessments. The objective of these reports was to provide a robust quality assurance (QA) framework for the development and verification of models used in the 2002 PCSC, including presentation of these tools using an assessment model flowchart to aid transparency. The Assessment Codes Review Group judged this work to be of a high standard, satisfying regulatory requirements with reasonable assurance (Galson Sciences Ltd and Environment Agency 2004h).

Only 2 of the 7 IAFs raised by this group included recommendations to LLW Repository Ltd. One of these was specific to codes that are not used in the 2011 ESC, and hence is no longer relevant. The remaining IAF, COD_007, is also not of relevance to the use of the GRM code in the 2011 ESC. However, the general principle applies in that the model should be adequately tested and that the testing should be fully documented. We recognise that an extensive programme of validation and verification has been carried out for GRM, and that the model appears suitably validated for a saturated system. However, we recommend that LLW Repository Ltd considers further work to support future GRM (or other near field code) modelling in relation to the partitioning of C-14 and the behaviour of C-14 in unsaturated vault conditions (Recommendation INF22).

LLW Repository Ltd's documentation of model and code QA in the 2011 ESC was less detailed than the 2002 PCSC. We raised this issue in IRF ESC-RO-ASO-007. In response, LLW Repository provided us with further information, allowing us to close the IRF.

3.11. Parameter IAFs

The 2002 PCSC Parameters Review Group raised a number of issues relating to the selection and substantiation of best estimate values for a number of key parameters and associated uncertainties (Galson Sciences Ltd and Environment Agency 2005b). We consider that the majority of these issues were either closed in the 2011 ESC or not relevant (for example, with regard to the emergence of land created by falling sea levels, which is no longer considered a credible scenario before site destruction).

IAFs relating to the assumption of homogenisation of waste material in human intrusion and coastal scenarios have been superseded by IRFs ESC-RI-ASO-010 and 011. LLW Repository Ltd addressed these issues to our satisfaction and these IRFs are now closed.

We noted that only a limited number of parameters were included in the 2011 ESC data management forms. All key parameters that are used in more than one part of the safety assessment (for example, hydrologically effective rainfall, HER) should be systematically defined, substantiated (including consideration of uncertainties) and documented (PAR_005.1 and Recommendation SCM18).

3.12. OESC IAFs

The 2002 OESC was presented separately from the 2002 PCSC and was prepared by a different contractor. This led to a significant divergence in approach to the preparation of the two submissions. Many of the comments from the 2002 OESC Review Group are directly related to this issue. Since the period of authorisation assessment (effectively the OESC) was fully integrated into the 2011 ESC, many of these comments are no longer relevant.

Although the linkage between the period of authorisation and post-closure assessments in the 2011 ESC is greatly improved, we raised concerns that separate assessments, with differing assumptions, were carried out for both periods for the groundwater pathway (IRF ESC-TQ-ASO-008). In response, LLW Repository Ltd provided further information that showed that projected

total radiological risk at the end of the period of authorisation is similar to that projected at the start of the post-closure period (Baker 2013). However, we note that earlier breakthrough of radionuclides such as Np-237 and Pb-210 is seen in the period of authorisation model. This allowed us to close the IRF. We recommend that there is better integration in future assessments (Recommendation ASS2). The correlation between the period of authorisation and post-closure non-radiological assessments was less good; this is discussed further in Environment Agency (2015f) and is taken forward in ESC-FI-006.

In OESC_003, we asked LLW Repository Ltd to consider further exposure pathways, including assessment of whether certain critical groups could be exposed to more than one pathway. We raised a similar issue in our review of the 2011 ESC (IRF ESC-RI-ASO-014). Further assessment presented by LLW Repository Ltd confirmed that projected doses were below $20 \mu\text{Sv y}^{-1}$ (Sumerling and Jackson 2013), allowing us to close the IRF.

A number of other issues raised in the IAFs link to similar issues raised in our review of the 2011 ESC. These include the following areas of work that we have asked LLW Repository Ltd to further develop in our FIs:

- Continue to monitor tritium in groundwater (OESC_006.1 and ESC-FI-002).
- Reassess its strategy for making the necessary improvements to the interim trench cap and demonstrating the use of BAT (OESC_006.2, OESC_006.4, ESC-FI-001 and ESC-FI-027).
- Carry out a programme of assessment and optimisation of the International Standards Organisation (ISO) freight containers to minimise potential releases to the environment from uncapped vaults (OESC_007.1, IRF ESC-RI-INF-005, ESC-FI-025 and ESC-FI-027).
- Develop the forward site engineering programme to make sure it produces the information necessary to meet the requirements of the GRA (OESC_007.3 and ESC-FI-026).
- Provide evidence of how the forward monitoring programme will be implemented and developed throughout the period of authorisation and linked to the ESC to reduce uncertainties wherever practicable (OESC_009.1, IRF ESC-RO-SUE-008 and ESC-FI-005).

In addition, we have raised one recommendation resulting from our review of the OESC IAFs that should be taken forward in any future iteration of the period of authorisation assessment:

- Future period of authorisation assessments should include a more thorough assessment of scenario, conceptual and parameter uncertainties (OESC_009.3, OESC_010.1 and OESC_011.1 and Recommendation ASS1).

3.13. Radiological capacity IAF

The Radiological Capacity Review Group concluded that the radiological capacity calculations provided by LLW Repository Ltd in the 2002 PCSC did not, on their own, provide a sufficiently robust basis for revising the quantitative disposal limits needed to support a change to the scope and extent of the disposal authorisation (Galson Sciences and Environment Agency 2005c).

Since the submission of the 2002 PCSC, we have worked with LLW Repository Ltd to ensure that the company derives a waste capacity based on the radiological limits documented in the ESC. We acknowledge that the approach used and nature of the radiological capacity calculations in the 2011 ESC are significantly different to those in the 2002 PCSC. Because of these differences, we have assessed the issues raised by the 2002 PCSC review team against the 2011 ESC radiological capacity and Waste Acceptance Criteria (WAC) only where applicable.

The Radiological Capacity Review Group identified good practice requirements for carrying out radiological capacity calculations to support the derivation of WAC and the 2005 permit (then authorisation) application. These included:

- linkage of the radiological capacity to the performance requirements of the GRA
- the robustness of the linkage between radiological capacity values and calculated risk throughout the entire ESC assessment period
- derivation of specific activity limits for key radionuclides

We consider that LLW Repository Ltd has satisfactorily taken these requirements into account in the 2011 ESC radiological capacity calculations.

We note that the review group stated that capacity is best expressed in terms of total inventory, but specific activity limits (that is activity per unit mass) should also be set so that doses potentially received from operational and post-closure scenarios would be tolerable (as is done in International Atomic Energy Agency (IAEA) 2004). LLW Repository Ltd has taken this into account and presents controls on total inventory (taking into account existing disposals and using a 'sum of fractions' method to take account of the combined impacts of all radionuclides) and specific activity limits for individual consignments (LLW Repository Ltd 2011; 2013c). The individual consignment limits allow the use of emplacement strategies, for example, the restriction of waste that will generate significant concentrations of radon from the upper stack positions. The company has also set out further controls on discrete items and higher activity particles (LLW Repository Ltd 2014).

4. Conclusions

We have reviewed the recommendations made during our review of the 2002 LLWR PCSC and OESC, as documented in the IAFs, against the progress summary provided by Sumerling et al. (2009) and information provided in the 2011 ESC. We also have considered information received from LLW Repository Ltd following submission of the 2011 ESC in the period leading up to the LLWR environmental permit variation application in October 2013.

There have been a number of significant changes to the LLWR ESC in the period between 2002 and 2011. Of particular relevance are:

- The understanding that the LLWR is almost certain to be destroyed by coastal erosion, with erosion commencing within a few 100 to a few 1000 years. Thus the 2011 ESC focuses on a much shorter timeframe than the 2002 PCSC.
- Significant effort has been directed at understanding past disposals, in particular disposals to the trenches in terms of activity, waste form, heterogeneity and location of key disposals.
- The engineering design of the facility, including future vaults and the closure engineering system, has been subject to extensive optimisation, resulting in updated designs.
- Increased computer power has improved the sophistication of the models used to project the behaviour of radionuclides in the disposal facility and the wider environment and estimate doses and risks.

Because of these changes, some of the issues considered to be outstanding at the end of our review of the 2002 ESCs, as documented in the IAFs, are no longer relevant. However, even in areas where understanding has significantly moved on, we have identified many general points of relevance to the 2011 ESC. Thus we classified only 27 of a total of 299 IAF recommendations as 'not relevant'.

Taking into account the entirely new safety assessment presented in the 2011 ESC, in which risks and doses are considered acceptable, and the improved focus on demonstration of optimisation, we have closed all the Core Review Group recommendations. We have made 6 recommendations to LLW Repository Ltd for future consideration and raised 1 FI asking the company to further develop its system for the management of uncertainties.

The 2002 PCSC included a more extensive assessment of engineering performance than the 2011 ESC. The Site Development and Engineering Review Group considered that the 2002 assessment may have been too complex. However, we consider that the 2011 assessment, which used a single engineering design and set of elicited parameters, will need further substantiation as it is developed further towards detailed design and construction. We have raised 7 FIs addressing the LLWR engineering forward programme. A total of 20 out of 36 IAF recommendations made by the Site Development and Engineering and Cap Review Groups are incorporated into these FIs.

The 2011 ESC near field assessment, which includes use of an updated version of the GRM code and increased inventory understanding as noted above, has advanced understanding of relevant features and processes in the near field compared with 2002. However, we consider that issues raised in a number of IAFs were not fully addressed in the 2011 ESC and could benefit from further work. We have raised these issues in 7 FIs. In addition, we have made 3 recommendations to LLW Repository Ltd for future consideration.

LLW Repository Ltd has significantly improved its understanding of the geology and hydrogeology of the LLWR and its environs since 2002. The company made use of new site investigation and monitoring data to update the conceptual geological and hydrogeological models and inform the development of a new 3D geological model and hydrogeological flow model. Some uncertainties remain, and we have raised 3 FIs requesting further work that LLW Repository Ltd could use to improve the characterisation and assessment of the geosphere. We have also made a total of 11 recommendations for further data collection and assessment to help reduce these uncertainties going forward.

The Biosphere Review Group considered that the approach to the treatment of the biosphere in the 2002 PCSC was broadly acceptable. The treatment in 2011 is simplified since there is no requirement to consider alternative climate states leading up to glaciation. We have closed all the IAF recommendations, although we have raised 1 related FI and made 8 recommendations for future improvements. Similarly, the Gas Review Group considered that the approach to the treatment of the gas pathway in the 2002 PCSC was broadly acceptable and we have closed all the GAS IAF recommendations. We have made 1 recommendation asking LLW Repository Ltd to review the assumptions and conclusions within the ESC when a decision has been made on the future of the closure cap gas vent.

Coastal erosion is the only disruptive event considered in the 2011 ESC. LLW Repository Ltd has carried out a significant body of work to understand the most likely timing of, and mechanisms for, coastal erosion of the LLWR. This led to development of a new, more robust model of coastal erosion, and estimation of doses during the period of erosion. Projected doses are below the risk guidance level. We have closed all IAF recommendations made by the Disruptive Events Review Group, although some fed into queries on the treatment of waste heterogeneity and potential exposure to higher activity discrete items and particles that we raised during our review of the 2011 ESC. Although the company adequately addressed these IRFs, we have raised 2 related FIs that ask for further assessment in this area. We have also raised a relevant FI, which asks LLW Repository Ltd to substantiate claims that the current post-closure engineered cap design, which includes a cobble layer to prevent bio-intrusion, will perform as intended.

Given that updated or new codes have been used in the 2011 ESC, most of the IAF recommendations made by the Codes Review Group are no longer relevant. We have made 1 recommendation in this area relating to the validation of GRM (or alternative near field codes) for the assessment of unsaturated conditions in the vaults.

Concerns relating to the document structure and supply of information were raised by both the Near field and Geosphere Review Groups. Although overall the documentation structure was much improved in the 2011 ESC compared with the 2002 PCSC, we shared some remaining concerns in these areas. In places, the audit trail for the near field information was poor, and we had to request other documents not included in the 2011 ESC as submitted. With regard to the geosphere area, development of several iterations of the geological and hydrogeological conceptual models and the 3D geological model in a relatively short period of time led to a loss of clarity in the 2011 ESC documentation and inconsistencies between the information used in the latest versions of these models and the groundwater flow model. We have made recommendations for improvements in these areas. We also consider that, although LLW Repository Ltd defined a suitable data management process for use in the 2011 ESC, the company did not use it sufficiently widely to ensure clarity of all data used in assessment calculations and substantiation of data provenance and associated uncertainties. We have made a recommendation for improvements going forward. The simplified process itself was, however, an improvement over the Parameter Input Form system used in the 2002 PCSC.

The 2002 OESC was presented separately from the 2002 PCSC and was prepared by different contractors leading to a divergence in approach to the preparation of the 2 submissions. Many of the comments made by the OESC Review Group relate to this issue and are thus no longer relevant since the assessments for the period of authorisation and post-closure period are more fully integrated within the 2011 ESC. However, a number of recommendations made in the IAFs link to similar issues raised in our review of the 2011 ESC and would benefit from further work as outlined in 7 FIs and 2 recommendations.

Only 1 IAF was raised by the Radiological Capacity Review Group, which we closed. We have identified some areas for improvement in our review of the 2011 ESC but have made no further recommendations resulting from the IAF.

IAFs will not be taken forward as a process for the management of issues associated with the LLWR ESCs. As described in this report, the majority of IAF issues have been adequately addressed or have become irrelevant to the 2011 ESC. All IAFs have now therefore been closed, although some IAF recommendations have been linked to FIs or new recommendations.

None of the issues that we have identified as benefitting from further work, as included in the FIs and new recommendations, are significant enough to prevent the 2011 ESC from meeting the requirements of the GRA (Environment Agency et al. 2009). However, we expect LLW Repository Ltd to develop and maintain a forward programme of work to ensure continued improvement to the ESC and continued compliance with our requirements. We will monitor progress against the FIs and will work with LLW Repository Ltd to ensure that its forward programme of work meets our regulatory expectations.

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6. Appendix 1. CORE IAFs

IAF no.	Title	Review group key comments and recommendations	LLW Repository Ltd response to comments and recommendations	EA comment on LLW Repository Ltd's position
COR_001	Independence of Safety from Control	<p>No recommendations, however:</p> <p>The Core Group (CG) was concerned over the possibility of disruption of the site by coastal erosion, related uncertainties, and statements in the 2002 PCSC indicating that credit might be taken for coastal defences. This would be inconsistent with GRA Principle 1.</p>	<p>COR_001 – Accepted / incorporated in our R2S9² submission</p> <p>More recent work on climate change and coastal erosion (Thorne and Kane 2007) has confirmed the likelihood of disruption of the site by coastal erosion.</p> <p>We agree that coastal defences are unlikely to be effective in the long-term and cannot be relied on in the ESC, and this was stated in our submission against Requirement 2 of Schedule 9, see (Baker et al. 2008b).</p> <p>The 2011 ESC will assess the expected progression of coastal erosion leading to disruption of the site, uncertainties in the progression and consequent impacts to humans and the environment. A case in which</p>	<p>COR_001 – Issue closed with recommendation</p> <p>We have considered this issue at great length within the Environment Agency and with LLW Repository Ltd and are content that the approach adopted by LLW Repository Ltd in the 2011 ESC is reasonable.</p> <p>An output of our review of the 2011 ESC is the expectation that LLW Repository Ltd will keep under review developments in observation and modelling of climate change and the evolution of the local coastline, and to ensure that the ESC continues to reflect the best evidence about the likely fate of the site (Recommendations SUE39 and SUE40).</p>

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R2S9 = Requirement 2 of Schedule 9 of the Authorisation.

IAF no.	Title	Review group key comments and recommendations	LLW Repository Ltd response to comments and recommendations	EA comment on LLW Repository Ltd's position
			the site is not disrupted by coastal will be treated as an illustrative 'what if' case.	
COR_002	Effects in the Future	<p>No recommendations, however:</p> <p>The CG considered that:</p> <p>Some of the arguments relating to the use of radiological capacity may not be consistent with GRA Principle 2 since they attempt to discount impacts that could arise beyond 10,000 years.</p> <p>The 2002 PCSC does not demonstrate that impacts on the health of future generations from the Drigg disposal facility will be less than relevant levels of impact that are acceptable today.</p> <p>More detailed criticisms refer to:</p> <ul style="list-style-type: none"> • treatment of uncertainties in the groundwater pathway • high risks from intrusion (especially due radon) • non-evaluation of non-radiological impacts 	<p>COR_002 – Mainly accepted / will be incorporated into the 2011 ESC.</p> <p>An alternative approach to calculation of radiological capacity was presented in Volume 2 of R2S9 submission (Baker 2008), and will be further developed, taking account of Environment Agency comments.</p> <p>We consider that radiological capacity should be based on those scenarios that are broadly expected, which includes human intrusion, but may exclude impacts at very long times when uncertainties make the results of doubtful significance.</p> <p>We acknowledge that the 2002 PCSC did not demonstrate that impacts below the 10^{-6} risk target.</p> <p>More realistic models of the groundwater pathway and of radon exposures related to human intrusion are liable to</p>	<p>COR_002 – Issue closed</p> <p>On radiological capacity, we agree with LLW Repository Ltd's general approach. The use of a sum of fractions based approach is in line with international practice. However, because of the extended operational period we expect LLW Repository Ltd to continue to align the radiological capacity with the developing ESC (Environment Agency 2015a). Given the expected lifetime of the LLWR (a few 100s to 1000s of years before coastal erosion commences), the recommendation to consider radiological capacities relating to impacts beyond 10,000 years no longer stands.</p> <p>We agree with LLW Repository Ltd's general approach to addressing uncertainty in the 2011 ESC, although we have raised some issues as described in Environment Agency (2015b). The 2011 ESC presents evidence for significantly lower risks and doses than those calculated in 2002, which are generally in line with guidance levels. This includes intrusion.</p> <p>LLW Repository Ltd has developed and presented a non-radiological assessment and capacity approach within the 2011 ESC. This provides the first evaluation of non-radiological impacts within the ESC. We have noted elsewhere that the approach is considered adequate, but with scope for continued</p>

IAF no.	Title	Review group key comments and recommendations	LLW Repository Ltd response to comments and recommendations	EA comment on LLW Repository Ltd's position
			<p>bring down the calculated risks and doses below those presented in 2002 PCSC.</p> <p>We believe, as stated in the GRA, that assessed risks above the 10^{-6} risk target may be acceptable provided that it is shown that the disposal solution is optimised.</p> <p>A preliminary assessment of non-radiological impacts has now been presented in (Barber and Henderson 2008). An improved approach to assessment of non-radiological impacts is currently being developed (Kelly and Applegate 2008), and will be discussed with the Agency, and thereafter included in the 2011 ESC.</p>	<p>improvement, particularly in terms of assessment clarity and consistency with other non-radiological assessments. The capacity approach seeks to control and characterise future non-radiological disposals to meet the assessment requirements. We note that this approach is designed to inform the ESC and will not form part of the permit requirements.</p>
COR_003	Optimisation and Best Practicable Means (BPM)	<p>The CG commented:</p> <p>The entire disposal facility is a single source in the context of dose and risk calculations. Hence, the risk target of 10^{-6} y^{-1} applies to all parts of the disposal facility.</p> <p>BNFL must provide a justification for any risks that exceed the risk target, in</p>	<p>COR_003 – Mainly accepted / Work ongoing that will be incorporated into the 2011 ESC.</p> <p>We accept that the entire disposal facility is a single source and the risk target applies to the site as whole.</p> <p>We accept that we must provide a justification for any</p>	<p>COR_003 – Issue closed</p> <p>The 2011 ESC addresses a much broader range of options than the 2002 ESCs. The analysis can be found in the Level 2 and Level 3 reports. Relevant decision criteria have been considered and cautious assumptions have been made where there is uncertainty in data.</p> <p>Within the 2011 ESC LLW Repository Ltd has considered the acceptability, or otherwise, of the various waste streams within the national</p>

IAF no.	Title	Review group key comments and recommendations	LLW Repository Ltd response to comments and recommendations	EA comment on LLW Repository Ltd's position
		<p>accordance with Principle 3 of the GRA.</p> <p>The erosion of the waste into the sea might be regarded as an unacceptable loss of containment and, therefore, of effective management control over the waste.</p> <p>The CG concluded that:</p> <ul style="list-style-type: none"> • the 2002 PCSC presents useful information on the possible performance of a range of risk management measures but that reservations remain regarding the range of options considered and the provision of information on social and economic factors • results should be provided for a broader range of risk management options • the 2002 PCSC does not demonstrate that the disposal facility has been optimised or that the radiological detriment is As Low As is Reasonably Achievable (ALARA) • hence, the 2002 PCSC does not show compliance with 	<p>risks that exceed the risk target, in accordance with Principle 3 of the GRA.</p> <p>We do not agree that disruption of the facility by erosion or any other mechanism constitutes 'unacceptable loss of containment'. The GRA places requirements related to protection of humans and the environment; containment is not a requirement. Management control is exercised during operations and up to the end of operator control. Beyond this time protection relies on the nature of the waste and engineered barriers.</p> <p>We accept that the 2002 PCSC did not present a sufficient exploration of facility design and risk management options and work is ongoing to correct this, for example see (Baker et al. 2008a).</p> <p>Response to recommendation COR_003.1;</p> <p>Work leading to the R2S9 submission considered a broader range of risk</p>	<p>inventory.</p> <p>The 2011 ESC does not present any risks that exceed the risk guidance level in the GRA.</p> <p>The 2011 ESC assumes repository disruption by coastal erosion. The predicted timescales for disruption occur after the period of authorisation. The 2011 ESC assesses the consequences of repository disruption against the requirements of the GRA and has presented evidence of compliance with these criteria.</p> <p>LLW Repository Ltd investigated the feasibility of future vault and trench waste retrieval in the 2011 ESC and concluded that the repository design would not prevent or hinder the future retrieval of either selected more hazardous waste items or consignments or the entire waste inventory. Within the 2011 ESC a specific assessment of selective trench retrievals was carried out as a potential means of risk reduction. This concluded that, based on ALARA, BAT and proportionality arguments, selective retrievals were not warranted at the time of the assessment.</p> <p>The 2011 ESC investigated the viability and benefits associated with coastal defences adjacent to and within the repository structure. It concluded that these measures will only delay coastal disruption and that future maintenance of these defences cannot be relied upon or taken credit for. The predicted delay in coastal disruption provided by coastal defences does not deliver significant radiological dose benefits and</p>

IAF no.	Title	Review group key comments and recommendations	LLW Repository Ltd response to comments and recommendations	EA comment on LLW Repository Ltd's position
		<p>GRA Principle 3</p> <p>Recommendation COR_003.1: Provide results from consideration of a broader range of risk management options than was considered in the 2002 PCSC. The risk management options to be considered should include one that involves future disposal of only short-lived radioactive waste, and another that combines future disposal of only short-lived radioactive waste with selective removal of those long-lived wastes in the trenches that contribute most significantly to site risk. As part of its optimisation work, BNFL should ensure an appropriate level of stakeholder involvement and should document an assessment of the relevant social and economic factors associated with the options considered.</p>	<p>management options (Baker et al. 2008b). Planned work will make more specific evaluation of options, see (Baker et al. 2008a).</p> <p>Consideration of options for future disposals will include assessment of acceptability (or not) of waste streams that contribute most to overall impacts. The future use of the LLWR will be addressed by National Strategy and Plans.</p> <p>We are currently considering options for selective retrieval of waste from the trenches and consequent detriments and benefits.</p> <p>We do not consider social factors per se since the distinction between options does not generate social differences. Costs and conventional environmental impacts will be considered in the evaluation of options. Results will be presented and discussed with stakeholders as appropriate.</p>	<p>could lead to detriments.</p> <p>LLW Repository Ltd has sought to optimise the repository, waste form, waste types, restoration and engineering design. The resulting repository disposal concept is considered to have been appropriately optimised. However, to implement the engineering design, LLW Repository Ltd will need to deliver a substantial engineering forward programme.</p> <p>We note that an outcome of the 2011 ESC and an ISO freight container condition and settlement investigation programme is the need to further examine the optimisation of waste protection prior to final capping (for example container design and waste protection) (Environment Agency 2015c). A number of FIs have been raised to seek further optimisation and engineering detail as work progresses (see, in particular, ESC-FI-001 and ESC-FI-026).</p>
COR_004 COR_005	Radiological Protection Standards:	No recommendations, however, the CG commented:	COR_004/5/6 – Accepted / Incorporated in the 2011 ESC	<p>COR_004, 005 and 006 – Issues closed</p> <p>The 2011 ESC integrates the period of</p>

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	Dose Constraint and Risk Target	<p>Dose constraint - before withdrawal of control:</p> <p>The 2002 OESC suggests that before site closure, a potentially exposed member of the public consuming contaminated groundwater adjacent to the site could receive a dose in excess of the dose constraint.</p> <p>The CG considers that the OESC and PCSC analyses should be consistent, and suggests that the two analyses could be merged into a single ESC.</p> <p>Risk target - after withdrawal of control:</p> <p>The CG is critical of the lack of an approach to integrating the results from the 2002 PCRSA in order to produce a risk estimate for comparison with the GRA. Even allowing for conservatisms, long-term site risks are likely to be significantly above the risk target.</p>	<p>Work is in hand to develop an improved modelling approach and assessment for the evaluation of wells.</p> <p>The 2011 ESC will present an integrated and consistent evaluation of impacts up to and beyond withdrawal of control.</p> <p>The 2002 PCRSA did not present an integrated evaluation of risk from all pathways or cases. We consider it informative and practical to keep the evaluation of different pathways separate. Risks should only be aggregated if they are risks to the same potentially exposed group. In the 2011 ESC we will provide overall risk estimates for pathways to which the risk target applies.</p> <p>We believe the 2002 PCRSA presented a pessimistic view of the long-term impacts as illustrated by results from the 2008 Performance Assessment (PA) update (Sumerling 2008). We acknowledge, however, that even with improved modelling and assessment some</p>	<p>authorisation and post-closure periods, although separate assessment calculations, with differing assumptions, were carried out for the 2 periods. We queried the integration of the calculations in IRF ESC-TQ-ASO-008. Calculated risks via the groundwater pathway during the period of authorisation, which include impacts associated with a well located close to and down hydraulic gradient of the LLWR, are below the operational dose constraint.</p> <p>Risks and doses calculated for the post-closure period are below the relevant guidance levels. We thus consider these issues closed.</p>

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			pathways may pose risks close to or above the risk guidance level.	
COR_007	No issue	-	-	-
COR_008	Multiple Factor Safety Case	<p>No recommendations, however, the CG commented: BNFL has made a reasonable interpretation of GRA Requirement R5, and have considered and documented information on a wide range of factors. However, because the 2002 PCSC suggests that impacts exceed the relevant dose constraints and risk targets by a significant margin, the CG considers that the safety case as a whole is not sufficiently robust, or optimised.</p> <p>The 2002 PCSC suggests that the Drigg disposal facility could exhibit 'cliff edge' effects, for example performance would deteriorate rapidly if oxidising conditions are re-established in the trenches, or if the site is destroyed by coastal erosion.</p> <p>These characteristics of the safety case and the disposal system at Drigg provide further</p>	<p>COR_008 – Mainly accepted / Approach is set out in the ESC approach report</p> <p>Illustration of the multiple factors that contribute to safety is an area in which we are planning to make improvements taking account of guidance in Chapter 8 of the revised GRA, for example considering safety functions. An approach is outlined in the ESC approach report (Baker et al. 2008a).</p> <p>Our assessments will consider changes in conditions, for example related to chemical changes and disruption by coastal erosion. It is the nature of a near-surface facility that it will be subject to changes, much more so than a deep geological repository. However, it is also a spatially extensive and heterogeneous system, so that different parts of the facility may be affected differently at different times.</p>	<p>COR_008 – Issue closed</p> <p>We agree that the 2011 ESC has considered a wide range of factors in accordance with the 2009 GRA (Environment Agency et al. 2009).</p>

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		support to the recommendation that consideration be given to a range of possible risk management measures for the repository, see IAF COR_003.	We consider 'cliff-edge effects' an inappropriate term and concept in this context.	
COR_009	Waste Form and Characterisation: Consistency with the PCSC	<p>The CG commented that the existing controls are based on previous safety assessments and other factors, their basis is not sufficiently transparent, and they may not be consistent with, the 2002 safety cases. The controls, including the Conditions For Acceptance (CFA), need to be reviewed and updated.</p> <p>Recommendation COR_009.1: Document the basis for the derivation of the CFA of waste at Drigg and update the CFA so that they are consistent with assumptions, models and parameter values in the most recent operational and post-closure safety cases.</p>	<p>COR_009 – Completed in respect of the 2002 safety cases / The determination of CFA is a major objective of the 2011 ESC</p> <p>Subsequent to the 2002 OESC and PCSC, a review was undertaken to determine whether the CFA were consistent with the assumptions and results of the 2002 PCSC (Barber et al. 2006). The extent to which current inventory limits are appropriate was discussed in the May 2008 submission to the EA (Baker 2008).</p> <p>An approach for the 2011 ESC with respect to post-closure impacts is outlined in the ESC approach report (Baker et al. 2008a).</p> <p>The determination of Conditions for Acceptance is considered to be a major objective of the 2011 ESC, and CFA will be revised to reflect</p>	<p>COR_009.1 – Issue closed</p> <p>After submission of the 2002 ESCs, LLW Repository Ltd undertook a review of consistency between the 2002 PCSC and CFA (Barber et al. 2006). LLW Repository Ltd has subsequently developed WAC for the LLWR; these have been revised following the 2011 ESC and subsequent work. We consider this issue closed.</p>

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			the outcome of the 2011 ESC, consistent with our Authorisation.	
COR_010	Records	<p>The CG commented on:</p> <p>Lack of evidence of a comprehensive system of records in the upper-level 2002 PCSC documents (although, a series of audits of BNFL's lower-level PCSC documents found the level and detail of checking by BNFL was comprehensive).</p> <p>BNFL's proposal to retain records for up to 37 years is insufficient because BNFL argues that the site should remain under active management control until ~2150.</p> <p>Lack of steps to ensure that duplicates of the records are kept in 'diverse' locations and in durable form.</p> <p>Recommendations:</p> <p>COR_010.1 Implement improved arrangements for records management to ensure retention of appropriately detailed information on all aspects of</p>	<p>COR_010.1 / 10.2 – Accepted / will be incorporated in the 2011 ESC</p> <p>The response to Schedule 9, Requirement 10 outlines the records management strategy (Dietzold 2007). The arrangements for all Records Management at LLWR are contained in the Repository Site Procedures (RSP). Specifically, RSP 5.01 (Records Management) contains the LLWR requirements and is fully implemented.</p> <p>A system of long-term records management will be proposed as part of the overall development of the 2011 ESC. The issue of record keeping beyond the period of authorisation and tenure of the SLC will be referred to the NDA.</p> <p>COR_010.3 – Accepted / will be incorporated in the 2011 ESC</p>	<p>COR_010 - Issue closed with recommendation</p> <p>We audited LLW Repository Ltd's process for record keeping in 2011. We were content with records management at the site, although some small improvements were required. We recommended that LLW Repository Ltd needs to review its records thoroughly post-delivery of the 2011 ESC (Recommendation SCM16). As part of routine regulatory activities we may follow up this process with further audits in the future.</p>

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		<p>the safety case until the withdrawal of institutional controls.</p> <p>COR_010.2 Transfer the Drigg disposal records on to durable media.</p> <p>COR_010.3 Provide formally documented records of the work of Clearing Houses and other groups involved in developing the safety case.</p>	<p>The system of 'clearing houses' is not being carried forward in the 2011 ESC. Rather a simpler but comprehensive database system is being initiated to record reference data values, uncertainties and source of all assessment data.</p>	
COR_011	Quality Assurance	<p>The CG commented that although the 2002 PCSC appears to have been developed under an appropriate QA regime, it is difficult and sometimes not possible to determine what QA measures were in place for individual pieces of supporting work.</p> <p>Recommendations:</p> <p>COR_011.1 Provide access to the RIMS and DTP Manuals for Agency review and audit.</p> <p>COR_011.2 Provide copies of procedures, instructions, and associated forms from the RIMS, R&T and DTP manuals, and any relevant internal and/or external audit reports,</p>	<p>COR_011 – Specific recommendations are no longer relevant / QA principles of defined procedures and traceability will be incorporated in the 2011 ESC</p> <p>QA documentation relating to the 2002 Safety Cases could be provided if requested by the Agency.</p> <p>Development of the ESC is carried out under the LLWR's QA system, which meets the requirements of ISO 9001. Appropriate subsidiary procedures, specific to the ESC Project, are being put in place.</p> <p>For the 2011 ESC, LLW Repository Ltd will be</p>	<p>COR_011 - Issue closed</p> <p>We agree that the specific recommendations are no longer relevant, although the general principle of the recommendations remain.</p> <p>We audited LLW Repository Ltd's quality assurance procedures in 2011 (Environment Agency 2011) and we audited quality assurance procedures specifically in relation to assessment of the groundwater pathways and modelling in 2013 (Fairhurst 2013). In general, we consider that robust quality assurance procedures are in place.</p> <p>We note that, although we concluded that the use of expert judgement in the development and use of elicited data in the 2011 ESC was appropriate (Environment Agency 2015b and 2015c), we have made a number of recommendations and raised FI ESC-FI-029 to request improved procedures for the future</p>

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		<p>particularly for those areas covered by: DTP/WI/012 DTP Conceptual Model Uncertainty Form; DTP/WI/013 DTP Parameter Input Form; DTP/WI/008 Clearing houses.</p> <p>COR_011.3 Provide procedure(s) for the use of expert judgement, or indicate which procedures and instructions from the RIMS and the DTP manuals cover the use of expert judgement, see also COR_024.3.</p> <p>COR_011.4 Provide evidence of independent checking of quantitative data (that is, provide documents showing what exactly was checked, how the checking was done and controlled, what proportion of the work was sampled, and what the results of the checking were).</p>	<p>documenting an assessment process and writing some overarching QA procedures that it will require contractors to work to when undertaking the assessment. This is an area in which we are currently working.</p>	management of elicited data.
COR_012	No issue	-	-	-
COR_013	Completion of Disposal	The CG considers that disposal of the wastes in the trenches and in Vault 8 will not be complete until the final site closure engineering is emplaced and, for example, the final site cap is	<p>COR_013 – Mainly accepted / A preliminary assessment of options is completed and a further study is planned leading into the 2011 ESC.</p> <p>We agree that disposal of</p>	<p>COR_013.1 – Issue closed.</p> <p>The ESC optimisation programme replaced the vertical drain concept with a solution that used the geological media below and adjacent to the vault for the dispersal of leachate after the failure of the engineered capping system. Additional</p>

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		<p>constructed.</p> <p>BNFL has taken account of the need to seal and close the disposal facility in its design. The CG infers that BNFL accepts that the process of optimisation applies to all parts of the Drigg disposal facility, including the trenches and the vaults.</p> <p>The CG considers that suitable techniques are available for construction of the closure components described by BNFL in the 2002 PCSC, but has not been able to find a demonstration of this in the documents of the 2002 PCSC.</p> <p>The CG is concerned that the vertical drain represents a proposal to intentionally contaminate groundwater at the site. BNFL will have to provide further justification for this design feature.</p> <p>Recommendation COR_013.1:</p> <p>To present additional information on the techniques to be used for constructing the site closure engineering.</p>	<p>wastes is not complete until the final site closure engineering is emplaced. We consider, however, that emplacement of waste at its intended disposal position is a significant step that is carried out under regulatory supervision and according to disposal standards of the time. Such disposal may not necessarily meet revised standards that are imposed later. In this case, decisions on the possible modification of an existing disposal or retrieval of waste should be taken in the context of optimisation and risk management considering the impacts from the site as a whole.</p> <p>The 2011 ESC will include consideration of options related to past disposals and will include information on site engineering closure methods and their practicality. The vertical drain is an option that is still under consideration.</p> <p>A preliminary assessment of site management options was presented in Edwards and Alexander (2005) and a further</p>	<p>capacity will be provided by an engineered horizontal under liner drainage layer located below the engineered lining system. The revised design has been appropriately optimised based on the prevention of near-surface discharges after cap failure.</p> <p>LLW Repository Ltd has presented within the 2011 ESC additional information on the techniques to be used for constructing site closure engineering. An optimised closure concept has been presented along with implementation plans. We expect LLW Repository Ltd to develop these plans further and to present further, more detailed designs over the coming years and prior to capping commencing. The company has prepared a forward engineering programme that includes this work (Shaw 2013). In FI ESC-FI-026 we set out our expectations for the nature and scope of the design and works needed to facilitate the construction of vault and trench closure systems.</p> <p>During our review of the 2011 ESC a number of design aspects requiring further optimisation have come to light that will influence site closure engineering and the optimised design.</p> <p>ISO freight container condition surveys have found that containers are in some cases more degraded than anticipated and that some contain unexpected voidage within the container. This will influence cap settlement and as a result LLW Repository Ltd has put in place a programme of work to assess the effects of container voidage</p>

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			<p>assessment of the status of options was presented in Baker et al. (2008b). A formal identification and evaluation of options leading to a Best Practicable Environmental Option (BPEO) study is planned for 2009, which will guide the site development plan for the 2011 ESC.</p>	<p>and to modify either cap design or the height of waste stacked to address this issue. We have raised FI ESC-FI-001 to seek further information on this issue as designs are reviewed.</p> <p>Following on from the 2011 ESC and the ISO freight container condition investigation, it has been identified that protection of the waste prior to capping needs to be re-visited, for example to consider container design and cap restoration sequencing. LLW Repository Ltd has instigated programmes of work in these areas. We have raised FI ESC-FI-025 to outline our expectations for this future work.</p> <p>The vertical drain design has been replaced with the horizontal basal drainage design concept described in the 2011 ESC. We address and review the performance of the revised drain design in Environment Agency (2015c).</p>
COR_014	Funding of Liabilities	<p>The CG commented there was inconsistency between BNFL's policy to ensure that funds are available to meet long-term liabilities and the statement that '...a long-term PCSC forward programme cannot be regarded as a commitment by BNFL nor the LMA [Liabilities Management Authority]³'.</p>	<p>COR_014 – Accepted / Cost information will be included in the 2011 ESC.</p> <p>The current Lifetime Plan assumes that the site will be managed by LLW Repository Ltd until the site is closed. The site will then revert to direct Nuclear Decommissioning Authority (NDA) control.</p>	<p>COR_014.1 – Issue closed</p> <p>We accept that Government is responsible for funding. LLW Repository Ltd provides cost estimates for the current Lifetime Plan⁴ period that it submits to the NDA for funding. We will continue to work with LLW Repository Ltd and NDA in reviewing funding provision.</p>

³ The LMA was a body formed immediately preceding the formation of the Nuclear Decommissioning Authority (NDA).

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		<p>The CG considers that the 2002 PCSC provides insufficient information on the level of resources required for the forward programme to develop future iterations of the safety cases, and provides inadequate assurance that the required resources will be available.</p> <p>Recommendation COR_014.1:</p> <p>Provide justified estimates of the costs for operating, closing and post-operational control of the Drigg site, including costs for the safety case.</p>	<p>Ultimately, the Government is responsible for providing funding and LLW Repository Ltd cannot provide guarantees.</p> <p>We will provide estimates of the costs for operating, closing and post-operational control of the LLWR site, including costs for the safety case, as part of the 2011 ESC.</p>	
COR_015	Overview of BNFL's FEP List and FEP Screening Information	<p>The CG raised a number of comments and concerns about BNFL's analysis of FEPs, particularly lack of information concerning FEPs categorised as 'subsumed', some unclear or poorly justified arguments for excluding FEP and EFEPs from the assessment, and the absence of a clear link between the FEPs categorised</p>	<p>COR_015 – Accepted / For the 2011 ESC a revised, simpler approach to FEP management will be adopted.</p> <p>We believe that formal FEP methodologies are helpful in expanding phenomenological consideration and checking completeness. We agree that the FEP methodology used in</p>	<p>COR_015.1 – Issue closed - subsumed into IRFs ESC-RO-ASO-004 and ESC-RO-ASO-005</p> <p>During the development of the 2011 ESC, we agreed with LLW Repository Ltd that a simpler approach to FEP analysis could provide a clearer demonstration of the essential aims of such analysis.</p> <p>A FEP and uncertainty tracking system was developed for the 2011 ESC (Lean and Willans 2010), which included a simplified FEP list.</p>

⁴ The 'Lifetime Plan' is a costed set of proposals for future work at the site, extending in detail for a number of years and less detail through to the anticipated site closure date and end of all site operations. This is provided by LLW Repository Ltd to the Nuclear Decommissioning Authority (NDA) as is the means by which funding for site operations are approved. ('Lifetime Project' is the project set up by LLW Repository Ltd to deliver the 2011 ESC).

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		<p>as 'included' and the equations implemented in the codes used for assessment calculations.</p> <p>The series of audits conducted concluded that although most assumptions were traceable, there was a lack of clear justification for some decisions and judgements, and the process of FEP identification and categorisation was complex.</p> <p>Recommendation COR_015.1: Specific suggestions for FEPs analysis including:</p> <ul style="list-style-type: none"> • a comprehensive site-specific list of FEPs • clearly-defined screening criteria to determine which FEPs to include in the PCRSA • clear and logically-justified reasons for all FEP screening decisions • document FEPs and models in a way that reduces uncertainty in the inclusion or exclusion of FEPs in PCRSA models • ensure consistency between PCRSA models and codes, 	<p>support of the 2002 PCSC was complex, and that this complexity may have tended to obscure traceability.</p> <p>We believe that given the experience from the 2002 PCSC and 2008 PA update, plus experience from other radiological safety assessments, we are now able to focus better on those FEPs that are most relevant to safety or that have the capacity to undermine safety. Hence, for the 2011 ESC we will be proposing an alternative, simpler approach to FEP management based on repository safety functions and more directly linked to models and the treatment of uncertainty. The methodology is outlined in Baker et al. (2008a).</p>	<p>However, a copy of the supporting database was not received until early 2013 (LLW Repository Ltd 2013).</p> <p>The treatment of FEPs in the assessment and associated uncertainties is adequately described in the tracking system. However, there is a lack of guidance on how the tracking system can be used to identify key uncertainties in the 2011 ESC and support the development of the forward programme to reduce these uncertainties. Similarly, we do not consider that the use of safety functions is well developed in the 2011 ESC. These issues were raised in IRFs ESC-RO-ASO-004 and ESC-RO-ASO-005. These IRFs have been satisfactorily addressed by LLW Repository Ltd. Thus we consider that this IAF can be closed. However, an FI has been raised to seek improved identification and management of key uncertainties (ESC-FI-008).</p>

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		and the results of the FEP screening analysis, and identify biases due to inconsistencies or model/code limitations		
COR_016	Scenarios, Pathways and Event Probabilities	<p>The CG considers that BNFL has assessed the consequences of the scenarios most likely to affect the LLW Repository at Drigg.</p> <p>The CG criticised the presentation of scenarios that were not certain to occur in terms of conditional risk, noting that BNFL has made some qualitative statements regarding scenario probability, but has not presented values of risk as defined in the GRA.</p> <p>Recommendations:</p> <p>COR_016.1 Clearly document and justify the selection of scenarios to be assessed in the PCRSA, including that a sufficiently representative set of scenarios has been assessed.</p> <p>COR_016.2 Provide information on the likelihood or probability of scenarios sufficient to support an understanding of radiological</p>	<p>COR_016 – Shortcomings of the 2002 PCSC are accepted / Related regulatory guidance has changed / We have outlined our approach for the 2011 ESC</p> <p>The strategy for addressing the four pathways – groundwater, gas, natural disruption and human intrusion – was outlined in the safety assessment approach document (Lean and Fowler 2007) and illustrated in the 2008 PA update (Sumerling 2008).</p> <p>The new GRA (Environment Agency et al. 2009) also makes statements regarding probabilities and assessment, especially of human intrusion that alter the position from that in 2002.</p> <p>We have outlined our approach to the classification of scenarios and to the treatment of natural events of uncertain occurrence or timing,</p>	<p>COR_016.1 and COR_016.2 – Issues not relevant</p> <p>These issues are specific to the 2002 PCSC and 1997 GRA (Environment Agency et al. 1997).</p> <p>COR_016.3 – Issue closed - subsumed into IRFs ESC-RI-ASO-010, ESC-RI-ASO-011, ESC-RI-ASO-012, ESC-RI-ASO-013, ESC-RI-ASO-014, ESC-RO-ASO-006 and ESC-TQ-ASO-009a</p> <p>A suitable range of scenarios has been considered in the 2011 ESC relating to the groundwater, gas, human intrusion and coastal erosion pathways. A broad range of PEGs has been considered for each pathway. However, we have specified additional PEGs to be considered, relating to assessment of:</p> <ul style="list-style-type: none"> • waste heterogeneity in coastal erosion dose assessment (IRF ESC-RI-ASO-010) • waste heterogeneity in human intrusion dose assessment (IRF ESC-RI-ASO-011) • dose calculations from marine foodstuff during coastal erosion (IRF ESC-RI-ASO-012) • human intrusion into radioactive sources (IRF ESC-RI-ASO-013) • total doses to a representative person during

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		<p>risk as defined in the GRA.</p> <p>COR_016.3 Assess potential exposures, doses and risks for all credible exposure pathways, including:</p> <p>A PEG living in housing constructed at the site near the waste after the cap has eroded.</p> <p>Use of contaminated well water by future site occupiers.</p> <p>Abstraction from a well, focusing flow of contaminated waters from the near-field.</p> <p>Upward flow and transport of radionuclides as a result of drain clogging and/or changing hydrogeological conditions.</p> <p>Radionuclide diffusion through the cut-off walls into streams.</p>	<p>and of human intrusion scenarios in the ESC approach report (Baker et al. 2008a). We will set out the scenarios that we plan to assess in advance of the 2011 ESC for EA comment. Detailed work has already been undertaken to define the characteristics of potentially exposed groups (Thorne 2007).</p>	<ul style="list-style-type: none"> the period of authorisation (IRF ESC-RI-ASO-014) doses that may arise from interactions with higher activity discrete items (IRF ESC-RO-ASO-006) the well pathway (IRFs ESC-TQ-ASO-009 and ESC-TQ-ASO-009a) <p>LLW Repository Ltd responded to these additional requests adequately such that we are satisfied that all credible exposure pathways have been considered.</p>
COR_017	No issue	-	-	-
COR_018	Modelling and Model Validation	<p>The CG commented that BNFL has suitable arrangements governing software quality assurance, but that not all of the assessment models have been peer reviewed.</p> <p>BNFL has taken some steps towards 'validating' its models</p>	<p>COR_018 – Accepted / Incorporated in the work leading to the 2011 ESC</p> <p>We have embarked on systematic programme of work leading to the 2011 ESC in which the models in use are being reviewed and developed</p>	<p>COR_018.1 – Issue closed with recommendation</p> <p>We consider that the information supplied on model quality assurance in the 2011 ESC was less comprehensive than that supplied in the 2002 PCSC. We raised the question about adequacy of software code quality assurance and the extent to which quality assurance</p>

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		<p>(that is, showing that they are 'fit-for-purpose'), but the CG considers that further work will be necessary to enhance confidence in the models. The CG made specific comments on each model being most critical of the model of groundwater flow and suggested alternative cases to be considered, for example related to erosion of the final site cap, repository flooding ('bathtubbing'), advection of gas via cracks in the site cap. Other IAFs were referred to.</p> <p>Recommendation COR_018.1:</p> <p>Adopt a strategic approach to, and implement a long-term programme for, building confidence in safety assessment and supporting models.</p>	<p>as needed and alternative models considered. An evaluation of the confidence in each model and its 'fitness-for-purpose' will be central to decisions on the models to be used in the 2011 ESC.</p> <p>A thorough review of cases to be considered will also be carried out, and justification of omitted (non-credible or unimportant) cases provided.</p>	<p>procedures have been applied to the modelling work in IRF ESC-RO-ASO-007. We also requested further information on how the various models interact and how model output is transferred between different models. This IRF was addressed to our satisfaction, but we recommend improved attention to this aspect of future ESCs and note that good practice would include provision of an assessment model flow chart, or similar, to illustrate the linkages and flow of information between the various models (Recommendation ASS27).</p> <p>We note that the use of environmental monitoring to reduce uncertainties in the ESC is addressed in IRF ESC-RO-SUE-007. This RO has subsequently been closed, although we have requested more information about how LLW Repository Ltd intends to develop the forward monitoring programme to address key uncertainties in the ESC in an FI (ESC-FI-005).</p>
COR_019	Presentation of PCRSA Results	<p>The CG was critical of the lack of an approach for integrating the results from the 2002 PCRSA in order to produce a risk assessment for comparison with the GRA, and also the lack of probabilistic calculations.</p> <p>The CG commented that</p>	<p>COR_019 – We disagree with the CG comments on the importance of PRA vs deterministic calculations / The 2011 ESC will include probabilistic calculations for key pathways and cases and coherent presentation of results from both.</p>	<p>COR_019 – Issue closed</p> <p>In the 2011 ESC, LLW Repository Ltd only undertakes a probabilistic risk analysis for the groundwater pathway, which focused on how risks in the well pathway vary under parameter uncertainty (Kelly et al. 2011). This is because the groundwater well is the limiting biosphere release path for the groundwater pathway, the pathway is amenable to probabilistic analysis,</p>

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		<p>probabilistic risk assessment (PRA) techniques can provide a better understanding of disposal system behaviour, a better means of focusing further research and assessment work on key uncertainties, and a more efficient path to demonstrating optimisation.</p> <p>The Core Group considers that BNFL should be more consistent throughout the safety case in presenting results for different performance measures (for example the same assessment timescale should be used for assessments of risk, collective dose, and impacts to non-human species).</p> <p>No recommendation under this IAF.</p>	<p>We accept that probabilistic calculations have an important role, especially to explore uncertainty, and we are planning to undertake probabilistic calculations of risk as part of the 2011 ESC for key pathways. We consider, however, that deterministic calculations of consequence, and estimates of probability, can yield estimates of risk suitable for comparison with the GRA guidance level and may be appropriate in some cases.</p> <p>Moreover, undue focus on probabilistic simulations can place emphasis on those uncertainties that are amenable to incorporation and consequent comparative neglect of other uncertainties.</p> <p>A balanced mix of deterministic and probabilistic calculations will be needed to explore repository performance and illustrate the effect of uncertainties.</p> <p>We disagree that PRA techniques provide a better understanding of disposal</p>	<p>and probability of a well is intrinsic to the analysis. The results are presented as annual risks for comparison to the risk guidance level. We queried the presentation of the output of the probabilistic assessment in IRF ESC-TQ-ASO-009 and ESC-TQ-ASO-009a. We were happy with the responses to these IRFs and thus consider that these IRFs can be closed. However, we note that we have asked LLW Repository Ltd to further consider the use of probabilistic calculations in groundwater pathway radiological capacity calculations in FI ESC-FI-012.</p> <p>We accept there are severe limitations in the use of probabilistic approaches for other exposure pathways.</p>

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			system behaviour, or a better means of focusing further work, or optimisation.	
COR_020	Treatment of Uncertainty	<p>The CG commented that assessments need to address three key sources of uncertainty related to scenarios, conceptual models, and parameters. BNFL has taken a systematic approach to identify uncertainties in each of these areas, and has evaluated some of the uncertainties. Overall, the CG considers that BNFL has not presented a sufficiently comprehensive or systematic evaluation of uncertainty. Nor has BNFL adopted a methodology that allows for the systematic propagation of uncertainties through the PCRSA calculations.</p> <p>More specific criticism were also given including related to:</p> <ul style="list-style-type: none"> • not quantifying scenario probabilities • the model of groundwater flow • justifications for conceptual models and lack of consideration of alternative 	<p>COR_020 – Accepted / Will be taken into account in analyses for the 2011 ESC</p> <p>We acknowledge that the 2002 safety cases present an incomplete evaluation of uncertainty.</p> <p>For the 2011 ESC, we will seek to comprehensively identify significant uncertainties and investigate those that are amenable to treatment, discuss those that are not, and thus present a balanced evaluation of uncertainties and their importance to performance.</p> <p>We acknowledge the 2002 safety cases present an incomplete evaluation of model sensitivities. We understand sensitivity analysis as a quantitative examination of how the behaviour of a system varies with parameter change. For the 2011 ESC, we will undertake focused sensitivity studies to understand behaviour and check the</p>	<p>COR_020.1 – Issue closed - subsumed into IRF ESC-RO-ASO-004</p> <p>Uncertainty in the assessment models used in the 2011 ESC is treated through use of a range of different cases for the main pathways. A probabilistic assessment calculation is carried out for the groundwater well pathway, and variant calculation cases are used to explore uncertainties in other key parameters. This is in accordance with standard practice for safety assessment.</p> <p>However, no formal register of significant uncertainties was provided in the 2011 ESC as submitted, as required by the GRA. Lists of 'key' or 'significant' uncertainties are provided in a number of the Level 2 and 3 reports but these do not appear to have been systematically identified and assessed. This issue was raised in IRF ESC-RO-ASO-004. Although, in response, LLW Repository Ltd provided sufficient information to allow us to close this IRF, going forward, we would expect to see a better linkage to assessment of conceptual uncertainty and uncertainty relating to alternative lines of reasoning, which would not be captured in the database in its current form. We would also expect to see a closer linkage to identified areas of concern in the ESC. We ask LLW Repository Ltd to provide a forward work programme which</p>

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		<ul style="list-style-type: none"> • models • selection of parameter values (both ranges and best estimate values) • lack of probabilistic analysis <p>Recommendation COR_020.1:</p> <p>Undertake an improved assessment of the expectation value of risk associated with the Drigg disposal facility, including a probabilistic treatment of uncertainty, and taking due account of the review comments and suggestions for further improvements contained in Environment Agency (2004), supporting reviews and the associated IAFs.</p>	<p>veracity of key models.</p> <p>We agree that probabilistic analysis has an important role and will seek to analyse key pathways through probabilistic calculations.</p> <p>Our approach in these areas is set out in the ESC approach report (Baker et al. 2008a).</p>	<p>identifies areas of further work needed to improve the FEP and uncertainty tracking system, or provide an alternative system as appropriate, in FI ESC-FI-008.</p>
COR_021	Structured Risk Assessment and the Forward Programme	<p>The CG commented that BNFL has applied a structured risk assessment to identify issues that may be included in the forward programme, and has used results from PCRSA to prioritise the forward programme. This is appropriate, but the CG notes and considers that:</p> <ul style="list-style-type: none"> • the Forward Programme Report only covers the 	<p>COR_021 – Partly accepted / A detailed plan of work leading to the 2011 ESC is in place / LLW Repository Ltd will advise the NDA on longer term needs but these must be judged by and remain the responsibility of the NDA.</p> <p>Risk assessments and supporting work are ongoing and an iterative approach can be used to continuously inform</p>	<p>COR_021.1 – Issue closed - subsumed into IRF ESC-RO-SCM-005</p> <p>We agree that the request for a detailed, costed forward programme may not be reasonable given the contractual arrangement with NDA. However, we expect LLW Repository Ltd to set out the key elements of the forward programme, up to the withdrawal of institutional control, that it assumed in the 2011 ESC and/or would recommend for the future management of the site, based on its knowledge and experience.</p> <p>The 2011 ESC only outlines possible areas for</p>

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		<p>period up to the next iteration of the PCSC, which BNFL suggests should be in around 10 years time, which the CG consider is an unacceptably long interval</p> <ul style="list-style-type: none"> • BNFL should document a commitment to a plan for a longer-term programme of work until withdrawal of active institutional control over the site and should put in place arrangements to ensure that this commitment is fully transferred to any successor organisation, such as the NDA • the forward programme described by BNFL is not sufficiently specific or detailed • the justification for some of the items proposed by BNFL as possible components of the forward programme is not clear • BNFL has not indicated the costs of the forward programmes or demonstrated that adequate funds will be available <p>Recommendation COR_021.1</p>	<p>and refine the forward programme. We consider, however, that 10 years is an appropriate interval between major PCSC/OESC or ESC iterations, on which formal regulatory review and amendment of the Authorisation may be based.</p> <p>LLW Repository Ltd will prepare and execute a forward programme of assessment and supporting work that relates to the duties of the SLC as determined by its contract with the NDA. The SLC will also advise the NDA with regard to longer-term site management needs and costs.</p> <p>LLW Repository Ltd has recently developed an ESC Lifetime Plan (LTP) that sets out our programme. This is more detailed than hitherto and provides the detailed basis for justification of LLW Repository Ltd's budget applications to the NDA.</p> <p>Assessed risk is important in deciding where effort is needed in improve to the ESC, but is not the only criterion. We</p>	<p>future work and in limited detail (LLW Repository Ltd 2011a). In IRF ESC-RO-SCM-005, we asked LLW Repository Ltd to prepare a more detailed forward plan, which will demonstrate how LLW Repository Ltd will deliver both known and anticipated requirements for forward work and also maintain awareness of scientific developments with a bearing on the ESC. A more detailed and adequate response was provided that outlines expectations for work in the longer term (Cummings 2011). Anticipated funding for such work is detailed within the LLWR Lifetime Plan. We accept that detailed plans cannot reasonably be defined beyond the next major review of the ESC.</p>

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		Present a more detailed and costed forward programme for further development of the Drigg environmental safety cases during the period until withdrawal of controls. Use risk-informed approaches to determine the priority for particular improvements to the safety case, and the priority for studies to be incorporated within the research and development (R&D) programme supporting the safety case.	take a rounded approach considering also scientific and stakeholder confidence in various aspects of the ESC and especially the potential for effective remedial actions and improvement of practice and design that could lead to reduction of impacts or increased efficiency of disposals.	
COR_022	Radiological Capacity	The CG commented that BNFL provides a description of their approach to calculating the radiological capacity of the future vaults, but this takes no account of the wastes disposed of in the trenches, which may dominate long-term risk. The CG also criticised that the calculations did not include all scenarios (esp. site termination events), do not adequately take into account the additive effects of disposed radionuclides, are not necessarily conservative and do not provide an expectation	COR_022 – Accepted / A revised method has been developed and will be applied in the 2011 ESC We accept that the calculation of radiological capacity should include appropriate consideration of past and future disposals and any scenario that is limiting on potential disposal capacity. In general, however, because of the characteristics of the system, total impacts are not estimated by adding the impacts for the trenches to those of the vaults.	COR_022.1 – issue closed The radiological capacity calculations in the 2011 ESC incorporate existing radiological disposals to the trenches and Vault 8 and stored waste in Vault 8 and Vault 9. LLW Repository Ltd has calculated radiological capacities for the groundwater pathway, the gas pathway and coastal erosion (that is, it has used all of the main PEGs and pathways to inform the radiological capacity). The company will manage capacity by applying a sum of fractions methodology, which will apply independently for each pathway. Additive effects of radionuclides have been considered and radiological capacity has been based upon appropriate dose and risk criteria.

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		<p>value of the risk associated with the entire site.</p> <p>Recommendation COR_022.1:</p> <p>Provide results from calculations of site radiological capacity that take full account of all of the wastes at the site, that account for the effects of site destruction events (coastal erosion, glaciation) and other potential exposure pathways, that account for the additive effects of the radionuclides present, and that are based on the expectation value of risk.</p>	<p>We illustrated a revised approach to calculation of radiological capacity in the R2S9 submission Volume 1 (Baker 2008). Our approach has been further developed taking account of EA comments on the R2S9 submission and an approach is set out in our 'Approach to ESC' report (Baker et al. 2008a) that takes account of both the CG's comments and the EA's more recent comments.</p>	<p>We agree with the general approach used by LLW Repository Ltd to manage radiological capacity. We will continue to interact with LLW Repository Ltd to make sure the adopted approach is being successfully applied.</p> <p>Also see RAD_001.</p>
COR_023	No issue	-	-	-
COR_024	Supply of Information	<p>The CG commented that:</p> <p>BNFL should adopt an iterative approach to future updates of the safety case, and demonstrate and communicate an understanding of the behaviour of the disposal system at an early stage.</p> <p>The Level I and II reports did not provide sufficient information to make the safety case or to enable a thorough assessment of their basis, and that underlying documents were delayed which protracted</p>	<p>COR_024 – Accepted / Comments taken into account in the planning of documentation for the 2011 ESC</p> <p>We appreciate the review comments and are taking account of them in the planning of documentation of the 2011 ESC. In particular, we agree that addressing the regulatory requirements is the primary objective of the ESC and these requirements should impact on the design and</p>	<p>COR_024.1 – Issue closed</p> <p>The 2011 ESC Level 1, 2 and 3 documents were delivered to schedule. We welcome the fact that none of the Level 3 ESC documents were protectively marked.</p> <p>COR_024.2 – Issue closed with recommendation</p> <p>We consider that the documentation provided in the 2011 ESC marks a significant improvement over the 2002 OESC and PCSC. This has aided regulatory review and assessment of conformance against the GRA requirements. However, there have been instances in which we consider insufficient information was presented</p>

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		<p>the review process.</p> <p>The relationships between the 2002 PCSC documentation and the regulatory requirements and guidance are not always apparent.</p> <p>There are many instances where the level of cross-referencing is either too sparse or insufficiently precise to follow lines of evidence easily.</p> <p>BNFL classified some of the information supporting the 2002 PCSC as 'commercial-in-confidence'; the Agency considers that the justifications given for classifying these documents were not always clear or sufficient.</p> <p>Recommendations:</p> <p>COR_024.1 Provide information in a timelier manner and that BNFL should strive to achieve the highest levels of openness.</p> <p>COR_024.2 Adopt a more strategic approach when planning the production of safety case and associated documentation, such that conformance with regulatory</p>	<p>presentation of the ESC.</p> <p>To make documentation comprehensive and fully traceable is a demanding task. By making documents on issues of concern to the EA available at an early stage, we aim to allow iteration and refinement to best meet EA requirements.</p> <p>We also have a work plan by which the underlying documents should be produced mainly in advance of the top-level submission, not in arrears.</p>	<p>in the main submission to 'make the case' and we have had to request additional documentation (for example, in the assessment of cap settlement performance presented in LLW Repository Ltd (2011b)). We also note that the delay in issuing some key information, such as the FEP and uncertainty tracking system that we did not receive until 20 months after the submission date (LLW Repository Ltd 2013), led to delays in our review.</p> <p>We recommend that LLW Repository Ltd ensures that all relevant information required to 'make the case' is included in the next ESC submission as far as possible (Recommendation SCM5).</p> <p>COR_024.3 – Issue closed</p> <p>Elicited data were used in the assessment of the long-term performance of the facility, in particular relating to the performance of the engineered barriers. A formal elicitation process was taken, using a group of subject matter experts in a workshop format. We consider this to be a suitable means by which to elicit such data. However, the documentation of this process is insufficiently comprehensive. The information provided to workshop attendees and minutes from the workshops were not presented as part of the ESC (Jackson et al. 2011). Despite this information not being part of the presented ESC, we are confident that the elicitation process was robust and comprehensive. Issues relating to the reporting of the data elicitation process</p>

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		<p>requirements is more directly addressed, and regulatory review and stakeholder dialogue are made easier.</p> <p>COR_024.3 Clearly identify and record the use of expert judgement in developing the safety cases. [see also COR_011.3]</p> <p>COR_024.4 Adopt an iterative approach when developing future updates of the safety case, and demonstrate and communicate an understanding of the behaviour of the disposal system at an early stage.</p>		<p>supporting the 2011 ESC are raised in Environment Agency (2015b and c).</p> <p>COR_024.4 – Issue closed with recommendation</p> <p>We believe that regular liaison between LLW Repository Ltd and the Environment Agency during the development of the 2011 ESC, including submission of the interim Requirement 2 submission (of Schedule 9 of the Environmental Permit), worked well and allowed us to gain confidence that the behaviour of the disposal system is understood. We recommend that such liaison continues to support the development of future ESCs (Recommendation SCM1). Additionally, we note that LLW Repository Ltd has proposed and established procedures to manage the ESC as a 'live' case, which will be updated and managed on an ongoing basis (see response to IRF ESC-RO-SCM-001). We consider that this will help to maintain and present an up to date picture of site understanding and behaviour.</p>
COR_025	Peer Review	<p>The CG commented that the BNFL peer review (Hill and Irvine 2003) was commissioned at far too late a stage, hence, not all of the peer review comments had been addressed when the PCSC was submitted. The CG considers that peer review should begin at an early stage</p>	<p>COR_025 – Accepted / An improved approach to peer review has been tested and is being applied during the development of the 2011 ESC</p> <p>We accept the shortcomings of the peer review process around the 2002 safety cases.</p> <p>We have appointed an</p>	<p>COR_025.1 – Issue closed</p> <p>During the development of the 2011 ESC, LLW Repository Ltd instigated two programmes of peer review.</p> <p>Firstly, an independent Peer Review Group (PRG), comprising a multi-disciplined group of suitably qualified and experienced reviewers, was set up in 2007 and was involved in review of the 2011 ESC development programme and of</p>

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		<p>and should be an active and continuous part of work leading to revision of the safety case.</p> <p>The CG also criticised BNFL description of the contribution of peer review to the safety case, and the lack of clear resolution to the peer review comments, which are rather critical. Reports containing the detailed findings of BNFL's peer review team were not provided to the Agency.</p> <p>BNFL's rejection of the main conclusion of its independent review team (BNFL 2003) reflects a lack of understanding by BNFL of peer review.</p> <p>Recommendation COR_011.1</p> <p>Implement an improved approach to peer review of the Drigg safety cases. The improved approach should include peer review beginning at an early stage in each iteration of the safety case, and BNFL should demonstrate that peer review comments have been adequately addressed.</p>	<p>independent peer review panel and implemented an improved approach to peer review of the safety cases and supporting work. This has been applied to the review of the recent R2S9 submissions.</p> <p>We value independent peer review as an important test and input to the development of the ESC. We note, however, that on occasions we may disagree with views from the peer review panel. We will identify and seek to resolve any such disagreement but ultimately responsibility for decisions on the direction and scope of the ESC lie with LLW Repository Ltd.</p>	<p>the 2011 ESC and supporting reports. This provided LLW Repository Ltd with the opportunity to respond to early concerns in subsequent technical work.</p> <p>In addition, an International Peer Review Group was convened with the aim of providing insights and perspectives from experts operating other disposal facilities (including LLW disposal facilities in Sweden, Spain and France) that would help the ESC Project team address issues being confronted in developing the 2011 ESC. This team assessed the Requirement 2 submission of Schedule 9 of the permit and the approach to the 2011 ESC (Baker et al. 2008a).</p> <p>We consider that the use of the PRG to support the ESC was consistent with international good practice and provides an example of the use of sound science in the ESC. The benchmarking of the developing ESC against international practice carried out by the International Peer Review Group (IPRG) was also a useful exercise. We welcome LLW Repository Ltd's commitment to continued use of a PRG to review the work of the ESC Team going forward.</p>
COR_026	Minimising	BNFL has observed two	COR_026 – Superseded / No	COR_026.1 – Issue closed

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	Radionuclide Releases via the Contaminant Plumes	<p>plumes of tritium contamination leading away from the Drigg trenches.</p> <p>The CG considers that the tritium plumes are more significant to the OESC than the PCSC because of the short half-life of tritium. BNFL acknowledges that it has not yet addressed the Agency's expectation that it should present an assessment of the best practicable means for minimising radionuclide releases via the contaminant plumes in either the OESC or the PCSC</p>	<p>equivalent requirement in the new near surface GRA.</p> <p>The Agency concern arises from the old GRA Requirement R3 (§ 6.23), that BPM 'shall be employed to ensure that any radioactivity coming from a facility will be such that doses to members of the public and risks to future populations are as low as reasonably achievable'.</p> <p>This was a general requirement. Any posited future doses arising from the existing tritium plume are within the dose guidance level for the period of authorisation. At the time of withdrawal of the authorisation any potential risk should be compared with the risk guidance level.</p> <p>Optimisation studies are planned as part of developing the ESC to ensure that doses and risks are ALARA.</p>	<p>LLW Repository Ltd has defined a compliance level for tritium consistent with the primary regulatory requirement of a dose limit of $20 \mu\text{Sv yr}^{-1}$. Monitoring of tritium reveals concentrations in groundwater have declined since the early 1990s. Although we consider this IAF to be closed, we note that we have raised a FI to require LLW Repository Ltd to maintain its monitoring programme throughout the operational period to record the nature and extent of the tritium plume, assess any differences between the plume and ESC assumptions and determine any effects as a result of future engineering (for example, surcharging) (ESC-FI-002). Also see OESC_006.2.</p>
COR_027	Supporting Arguments	<p>No recommendations, however, the CG commented:</p> <p>On multiple lines of reasoning, many of BNFL's arguments are irrelevant, misleading or inaccurate, for example,</p>	<p>COR_027 – Largely rejected or superseded</p> <p>We accept that the presentation of arguments may have been weak in the 2002 OESC/PCSC, we consider that</p>	<p>COR_027 – Issue closed</p> <p>Agreed.</p> <p>LLW Repository Ltd has presented multiple and supplementary lines of argument to support the 2011 ESC. In particular it has presented relevant</p>

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		<p>related to the national interest, the Health and Safety Executive's Tolerability of Risk, stakeholder engagement, insufficient analysis of the uncertainties, optimisation.</p> <p>With regard to sustainable development, the CG has concerns that the potential for destruction of the Drigg site by coastal erosion in the relative near-term means that, it may create undue burdens on future generations. In addition, erosion of the waste into the sea might be regarded as an unacceptable loss of containment and management control over the waste.</p> <p>With regard to the Precautionary Principle the CG considers that the key issue centres on the potential for site destruction by coastal erosion and the question 'is it sensible to dispose of radioactive wastes where they might be eroded into the sea?'</p> <p>The Core Group notes that even though it was not the aim of the 2002 PCSC to demonstrate that disposal at</p>	<p>the ESC should present a full range of arguments and evidence as required by the new GRA.</p> <p>In the 2011 ESC we will focus on technical multiple and supplementary lines of reasoning to support confidence in the ESC and compliance with the new near surface GRA, as outlined in Baker et al. (2008a).</p> <p>We reject the comments that the threat due to coastal erosion is incompatible with the principles of sustainability or precaution.</p> <p>The nature of near-surface disposal at any site is that the disposed material will at some time in the future be exposed and distributed in the biosphere by natural processes, human actions or both. Hence, the waste disposed must be such that at times when this could happen (and taking account of possibilities for how it might happen), doses and risk are acceptably low, that is comparable to the risk and</p>	<p>arguments for the potential destruction of the site by coastal erosion.</p> <p>The 2011 ESC has demonstrated that doses and risks for all reasonable scenarios and at all reasonable timescales remain acceptably low compared to guidance levels in the GRA. The 2011 ESC therefore supports the permit variation.</p>

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		<p>Drigg represents the BPEO for the management of the UK's low-level radioactive waste, this demonstration remains to be made.</p> <p>BNFL's arguments regarding background radiation are discussed in IAF BIO_004.</p>	<p>dose guidance level specified in the GRA.</p>	
COR_028	Waste Retrieval	<p>No recommendations, however, the CG commented:</p> <p>Once the plutonium contaminated material currently on the Drigg site has been removed, it will have no effect on the long-term safety of the repository.</p> <p>BNFL has not provided information to support its assertions regarding the difficulty and costs of waste retrieval.</p> <p>The safety case should be used to help determine the appropriate response to the threat of coastal erosion at Drigg.</p> <p>The CG has reservations regarding BNFL's argument for deferring consideration of waste retrieval.</p>	<p>COR_028 – Accepted / Preliminary study accomplished and detailed work in hand to address the question of selective waste retrievals</p> <p>Since 2002, we have made an initial study of retrieval of waste from the trenches considering three broad options – retrieve all waste, partial disturbance and leave undisturbed. The main conclusion is that complete retrieval would entail grossly disproportionate cost and is not appropriate (Baker et al. 2008b).</p> <p>A study is now underway that is looking at the post-closure amelioration, detailed operational requirements / practicalities and cost of specific options for focused</p>	<p>COR_028 – Issue closed - subsumed into IRF ESC-RI-ASO-003</p> <p>LLW Repository Ltd has considered a range of risk management options and made a case within the 2011 ESC for not retrieving any of the trench wastes at this time.</p> <p>The 2011 ESC notes that retrieval of all trench wastes is within current industrial capability. We sought a similar assurance that current and future development of the LLWR would not preclude the possibility of waste retrievability from the vaults, nor make retrievability unnecessarily difficult for future generations (IRF ESC-RI-ASO-003). In response, LLWR Repository Ltd provided assurance that there is nothing in the current design or future plans that would hinder or preclude future generations from retrieving wastes or even developing sea defences adjacent to the site, either as part of a deliberate action in relation to the LLWR or as part of wider plans for coastal management in Cumbria (Egan 2011).</p> <p>The 2011 ESC has demonstrated that there is</p>

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		BNFL should consider a range of risk management options, including one that involves selective removal of those long-lived wastes in the trenches.	and selective retrieval from the trenches. Results from these studies will inform an optimisation study considering a wide range of options.	<p>no clear requirement for actions to be taken with regard to coastal erosion at this time. Throughout the period of authorisation, the ESC should provide future generations with sufficient understanding of the nature of historic and future disposals to allow determination of response to the treat of coastal erosion based on contemporary safety, social and economic factors.</p> <p>Also see our response on COR_003.</p>

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7. Appendix 2. SDE IAFs

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
SDE_001	Site Development and Engineering Adequacy of Information / Referencing	<p>SDE_001.1 Provide quantitative evidence to demonstrate that the performance of the engineered clay layer under Vault 8 will be sufficient such that the Pebby Clay Formation can be regarded solely as an assurance measure for the control of leachate and is not needed for compliance.</p> <p>SDE_001.2 Provide appropriate performance data for a range of compositions for the surrounding cut-off wall to demonstrate that the properties assumed in PCRSA calculations will be achievable.</p>	<p>SDE_001.1 – Accepted / in hand or planned for the 2011 ESC The sensitivity of the safety assessment to the performance of the engineering components, including the Vault 8 engineered clay layer will be assessed as part of the 2011 ESC.</p> <p>SDE_001.2 – Accepted / work complete The Engineering Performance Assessment for the 2002 PCSC has been revisited (Paksy 2008) to provide performance data for the engineering components including the proposed cut-off wall design (Carpenter and Proctor 2007). The Institution of Civil Engineers (ICE) specification for bentonite slurry walls (ICE 1999) suggests a hydraulic conductivity of $1E-09 \text{ m s}^{-1}$. This is taken to be the best estimate for the initial 'as</p>	<p>SDE_001.1 – Issue closed The 2011 ESC is not dependant on the performance of engineered clay under Vault 8 to achieve compliance and the presence of the Pebby Clay Formation will only provide additional reassurance and attenuation. This IAF specifically refers to the radiological safety performance. The 2011 ESC includes an assessment of the non-radiological impact of the repository. For the non-radiological assessment, the presence of the engineered clay under Vault 8 delivers an equivalent performance to a non-hazardous landfill basal engineering system.</p> <p>SDE_001.2 – Issue closed The surrounding cut-off wall has a revised role in the single dome optimised design. Rather than acting as a barrier to lateral off-site groundwater migration, the cut-off wall allows the maintenance of a lower groundwater height and control of groundwater height within the annulus of the surrounding cut-off wall. The design is intended to direct leachate into deeper groundwater. The revised functionality requirement for the cut-off wall is based on provision of low hydraulic conductivity. The hydrogeological modelling presented within the 2011 ESC is based on hydraulic conductivity performance rather than</p>

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			placed' performance.	attenuation. This modelling demonstrates that the revised cut-off wall design should provide appropriate low hydraulic conductivity performance over the required time period.
SDE_002	Site Development and Engineering Screening, Model Development and Assumptions	<p>SDE_002.1 Present more information on the effect of key assumptions in the Level II documents. Specifically, provide justification for the assumption that the properties of all engineered features converge to a single value at a specific time.</p> <p>SDE_002.2 Assess the effect of alternative conceptual models regarding the evolution of engineered features, specifically the inclusion of assumptions regarding component behaviour that could lead to 'over-topping'.</p> <p>SDE_002.3 Conduct integrated uncertainty analyses that link uncertainties in near-field evolution to uncertainties in the properties of the geosphere.</p> <p>SDE_002.4 Use the results of modelling studies of the engineered</p>	<p>SDE_002.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>The assumption of the engineering components becoming 'hydrogeologically indistinguishable' is no longer considered to be justifiable given the reduced timescales being considered due the effects of coastal erosion.</p> <p>SDE_002.2 and SDE_002.3 – Accepted / in hand or planned for the 2011 ESC</p> <p>Paksy (2008) presents the updated engineering performance assessment model and details of the expert elicitation process that has been undertaken to derive property values over the lifetime of the repository. The behaviour of the engineered system as a whole will be considered using both the site-scale model and a GoldSim model as part of the 2011 ESC taking into account both the</p>	<p>SDE_002.1 – Issue carried through to FIs ESC-FI-026 and ESC-FI-027</p> <p>The site development and engineering information presented in the Level 2 documents of the 2002 PCSC have been superseded. Comments here relate to the information presented as part of the 2011 ESC.</p> <p>Elicited performances of various components of the engineered system are presented by Jackson et al. (2011). These include time-dependant reductions in performance. For engineered clay elements of the barrier systems, reduction of performance to a point where it is indistinguishable from the surrounding geology is unlikely to occur prior to the erosion of the repository.</p> <p>The performance values presented are considered adequate for the purpose of the ESC. During the design and construction of the engineered systems we will be seeking a reduction in the reliance of elicited performance values to values based on empirical evidence wherever practicable and beneficial to do so.</p> <p>We ask LLW Repository Ltd to develop an engineering performance assessment framework in FI ESC-FI-026. Such an assessment framework should be able improve quantification</p>

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		features to assess the cost-effectiveness of the proposed components (for example the over-waste drainage blanket).	<p>uncertainty in the evolution of the engineering features and uncertainties in the properties of the geosphere.</p> <p>SDE_002.4 – Accepted / in hand or planned for the 2011 ESC</p> <p>The 2011 ESC safety assessment will consider the cost effectiveness of the proposed components and optimisation of the design.</p>	<p>of the nature and extent of engineering material performance after localised failures.</p> <p>SDE_002.2 – Issue carried through to ESC-FI-026 and ESC-FI-027</p> <p>The 2011 ESC uses a single conceptual model that assumes that the capping system will degrade to a point at which the rate of inflow into the repository will exceed the rate of vertical hydraulic conductivity through the basal liner. These assumptions are based on elicited performance values for the engineered components. When the capping system fails, leachate will accumulate in the base of the repository.</p> <p>The 2011 ESC design for future vaults incorporates a 1 m low permeability wall on the western edge. When leachate accumulates, it is designed to overtop the 1 m walls and enter the adjacent geology and the basal drainage system thus avoiding overtopping and release of leachate to near-surface pathways. The potential for overtopping of Vaults 8 and current Vault 9 is potentially greater as they do not incorporate this design element. We will be seeking confirmation from LLW Repository Ltd that the leachate originating from Vault 8 and Vault 9 can be dispersed to, and then by, the basal drainage system prior to closure of these vaults. This will form part of the LLW Repository Ltd leachate management strategy requested in ESC-FI-023.</p> <p>We are satisfied that the engineering design presented in the 2011 ESC can work as</p>

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				<p>intended. However, to increase confidence, in FIs ESC-FI-023 and ESC-FI-027 we seek additional reassurance and design validation for the engineering components. Of particular interest is the possible future location, timing and extent of cap failure and its ability to perform as predicted within the 2011 ESC. This issue thus remains open and subject to ongoing discussion with LLW Repository Ltd as the detailed designs are developed in the run up to vault closure.</p> <p>SDE_002.3 - Issue closed</p> <p>Assessment of uncertainty in the engineered system and near field environment, and the effect on near field flows, is carried out within the 2011 ESC using the compartmental flow model (Hartley et al. 2011a) and the groundwater pathway assessment model (Kelly et al. 2011). The chemical evolution of the near field is modelled using GRM. Uncertainty in certain near field properties is characterised by probability density functions (PDFs) presented by Jackson et al. (2011).</p> <p>SDE_002.4 - Issue closed</p> <p>We consider this IAF question closed as the optimisation process carried out by LLW Repository Ltd has been carried out in accordance with the requirements of the GRA and has considered costs and effectiveness of engineering components.</p>
SDE_003	Site Development	SDE_003.1 Provide quantitative results from	SDE_003.1 – Accepted / in hand or planned for the 2011	SDE_003.1 – Issue carried through to FI ESC-FI-026 and ESC-FI-027

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
	and Engineering Treatment of Uncertainty	<p>PCRSA calculations to demonstrate the effect on overall system performance of a range of overall designs and sub-system options.</p> <p>SDE_003.2</p> <p>Provide more detailed uncertainty analyses (for example, probabilistic calculations) to provide a better understanding of system behaviour and to ensure that the full range of potential system behaviour has been examined.</p> <p>SDE_003.3</p> <p>Integrate the treatment of uncertainty in the near-field with the treatment of uncertainty in the geosphere to avoid making unrealistic assumptions about the evolution of the engineered features.</p>	<p>ESC</p> <p>Demonstrating the link between the behaviour of the engineering components, water movement within the wastes and the movement of water into the geosphere is recognised as being important in the development of the 2011 ESC.</p> <p>SDE_003.2 – Accepted / in hand or planned for the 2011 ESC</p> <p>The system behaviour will be assessed using a combination of the a GoldSim model of the near field taking into account the EPA work by Paksy (2008) and the site-scale model (Henderson et al. 2008). Probabilistic calculations will be undertaken to ensure that the full range of potential system behaviour is considered.</p> <p>SDE_003.3 – Accepted / in hand or planned for the 2011 ESC</p> <p>The 2011 ESC will ensure that a consistent approach to the treatment of uncertainty and the assumptions made about</p>	<p>With specific regard to the treatment of uncertainty in site development and engineering, we have queried the scope and approach used in the 2011 ESC to demonstrate the performance of engineering systems and suggested some areas for ongoing development (Environment Agency 2015a and FIs ESC-FI-026 and ESC-FI-027).</p> <p>The 2002 PCSC included a substantial EPA that investigated the performance of engineering systems and the associated effect on site safety. The scope of uncertainty and engineering performance assessment in the 2011 ESC was reduced as a result of probable early site disruption by coastal evolution removing the need for a longer-term EPA. Although the assessment presented is adequate, we seek further improvements in the understanding of uncertainty and failure/performance change in the engineering system. LLW Repository Ltd's engineering forward programme and the development of a more detailed design in the run-up to construction will provide an opportunity to investigate more detailed aspects of uncertainty associated with system behaviour.</p> <p>SDE_003.2 – Issue carried through to ESC-FI-026 and ESC-FI-027</p> <p>The 2011 ESC groundwater pathway assessment calculations included elicited temporal changes in the hydraulic conductivity performance of engineering systems. Probabilistic assessment is used, but we</p>

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			the evolution of the engineered features.	<p>consider that the assessment could be improved further by the consideration of potential engineering failure scenarios. We do not consider such an assessment essential in making the ESC, but we seek to understand better the relative importance of engineering systems in delivering their safety functions.</p> <p>SDE_003.3 – Issue closed</p> <p>Uncertainty is integrated into the 2011 ESC with the use of a compartmental flow model (Hartley et al. 2011a) and groundwater pathway assessment model (Kelly et al. 2011). A common set of elicited data for both the near field and engineering values are used (Jackson et al. 2011). Minimum, most likely and maximum values have been elicited and used in the assessment. The predicted reduction in engineering system performance with time is quantified with elicited performance values at appropriate intervals throughout the lifespan of the LLWR. This approach replaces the use of probabilistic analysis of long-term engineering performance degradation.</p> <p>We note that different FEPs are presented for the engineering system design and the engineering design performance. We would prefer better integration of the 2 types of engineering uncertainty.</p>
SDE_004	Design Justification	SDE_004.1 Assess the effect of any proposed design options on	SDE_004.1 and SDE_004.3 – Accepted / in hand or planned for the 2011 ESC	<p>SDE_004.1 - Issue carried through to ESC-FI-026</p> <p>We consider that optimisation was used</p>

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		<p>overall system performance and not restrict optimisation studies to the performance of individual components.</p> <p>SDE_004.2</p> <p>Demonstrate either that the bath-tubbing drainage system is likely to function as intended at the appropriate time or, if not, that the failure of the system is represented in the scenarios considered in the PCRSA modelling.</p> <p>SDE_004.3</p> <p>Demonstrate that the joints between the existing Vault 8 walls and the vertical extensions will have an appropriately low permeability to prevent lateral migration of leachate and so not compromise the intended function of the over-waste drainage blankets.</p> <p>SDE_004.4</p> <p>Justify the selection of the proposed composition for bentonite enhanced soils.</p>	<p>As discussed in SDE_003 and SDE_004 the overall performance of the design options will be considered as part of the 2011 ESC.</p> <p>SDE_004.2 – Accepted / in hand or planned for the 2011 ESC</p> <p>The behaviour of the drainage system will be considered as part of the assessment of the overall performance of the engineering components.</p> <p>SDE_004.4 – Accepted / in hand or planned for the 2011 ESC</p> <p>Carpenter and Proctor (2007) provide details used in the selection of the engineered properties required for the Single Design Option. The 2011 ESC will consider how the proposed engineering affects the overall performance of the site.</p>	<p>appropriately in the 2011 ESC to assess options and inform the development of the repository design.</p> <p>Optimisation was carried out in support of the design of engineered barriers. The optimisation process specifically identified discriminators in the ability of engineered barriers to provide safety functions at relevant times.</p> <p>Assessment of the quantitative performance of various components of the engineering system was considered during the optimisation process (see Appendix E of Paultey and Egan 2011, which also refers to modelling carried out by Hartley et al. 2011b). It was as a result of this optimisation work that the engineering design was updated from that proposed as part of the 2002 ESCs. For a number of the functional assessments such as leachate minimisation and direction of releases, optimisation was carried out on the repository design and not individual components.</p> <p>We are satisfied that the optimisation approach has been carried out appropriately for the current stage of development of the LLWR. Nevertheless it lacks a comparison of assessment outputs from specific design elements such as the drainage system. This assessment would be useful, but is not essential to the robustness of the 2011 ESC. We will seek improved understanding of the effects of performance differences for different design elements as the engineering design evolves</p>

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				<p>prior to construction. We will also expect to see improving understanding of long-term performance via the engineering forward plan (ESC-FI-026).</p> <p>SDE_004.2 - Issue carried through to ESC-FI-026</p> <p>Overtopping of the vault walls (or 'bathtubbing') is expected in the long-term. The optimised engineering design has incorporated specific engineering features in the future vaults to manage and mitigate the effects of overtopping. This comprises an engineered horizontal drainage layer in combination with natural granular material providing a preferential flow path from the waste mass. This design is not present in the trenches, Vault 8 and the currently constructed Vault 9.</p> <p>During our review of the 2011 ESC, we have queried and received adequate responses with regards to the performance assumptions used for the design and assessment of the overtopping engineering features (Environment Agency 2015a). In ESC-FI-026 we set out our expectations for a forward engineering programme. LLW Repository Ltd has committed to a forward programme of work that will include investigations into the long-term performance of key engineered features and the engineering materials within them.</p> <p>SDE_004.3 - Issue not relevant</p> <p>Design element no longer applicable. As part of</p>

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				<p>the design justification process, LLW Repository Ltd will need to develop and assess the performance aspects of the interface between the capping system and the waste body.</p> <p>SDE_004.4 - Issue carried through to ESC-FI-026</p> <p>The Bentonite enriched soil (BES) component of the Vault 9 basal lining system was designed to the required performance specification. The construction of Vault 9 was carried out in advance of the 2011 ESC. The performance requirements were thus based on the performance specification set out in the 2002 PCSC and subsequent work. The installed BES was tested and validated as achieving the required as-built performance. This performance has been used in the 2011 ESC performance assessment.</p> <p>The design and composition of the BES proposed for the future basal lining and capping systems will be developed further during the engineering design process leading up to construction. We expect appropriate demonstration of as-built performance in line with design expectations and equivalency to the 2011 ESC performance assumptions. ESC-FI-026 addresses our expectations for continued work in this area.</p>
SDE_005	Engineering Performance Assessment -	SDE_005.1 Modify the complexity and/or resolution of the EPA approach	SDE_005.1 – Accepted / in hand or planned for the 2011 ESC	<p>SDE_005.1 - Issue carried through to ESC-FI-026</p> <p>The complexity of the 2002 EPA was questioned</p>

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	Methodology	<p>to better reflect its overall purpose.</p> <p>SDE_005.2</p> <p>Either justify why elicited uncertainties on the time required for the properties of engineering features to become indistinguishable from those of the surrounding geology were not propagated through the 2002 EPA and PCRSA calculations, or provide PCRSA results that account explicitly for the uncertainties in the degradation rates of the engineered features.</p> <p>SDE_005.3</p> <p>Either justify why all the scenarios of near-field evolution considered in the EPA have not been carried forward to the PCSC, or provide PCRSA results for the scenarios omitted from the 2002 analyses.</p> <p>SDE_005.4</p> <p>Improve the transparency and traceability of the EPA by providing additional information and explanations for topics including:</p> <p>The terminology used for the</p>	<p>The EPA has been updated since the 2002 PCSC (Paksy 2008) and selection of parameter values for the 2011 ESC will be revisited to ensure that any changes over time are consistent with the evolution of the site.</p> <p>SDE_005.2 – Some work undertaken / superseded</p> <p>Paksy (2008) provides more detail on the justification of each parameter value. As noted in SDE_002.1, the assumption of the engineering components becoming ‘hydrogeologically indistinguishable’ is no longer considered to be justifiable given the reduced timescales being considered due the effects of coastal erosion.</p> <p>SDE_005.3 – Accepted / in hand or planned for the 2011 ESC</p> <p>The 2011 ESC will ensure that a consistent approach is maintained between the scenarios considered in the EPA and those in the ESC safety assessment.</p>	<p>by the Cap Review Team. The 2011 ESC addressed design assessment using a different and less complex approach.</p> <p>The 2011 ESC considers a single conceptual design and set of elicited performance assumptions (distributions were elicited for barrier properties as a function of time on the basis of certain assumptions). Due to the likelihood of coastal disruption of the facility, with disruption commencing within a period of a few 100 to a few 1000 years, the engineering systems will only need to function over a shorter period of time with fewer longer term failure mechanisms requiring detailed consideration. These factors have simplified the engineering design assessment process. We comment on the appropriateness of the engineering performance assessment in Environment Agency (2015a).</p> <p>We also note that the assessment assumes that the cap loses its ability to significantly control infiltration after a period of several hundred years. This is conservative and removes the need to assess a range of cap failure mechanisms.</p> <p>During our review of the 2011 ESC, we questioned the simplified approach to assessment of engineering performance and its ability to identify realistic failure mechanisms (IRF ESC-RO-SUE-009). We noted that the 2011 ESC did not make full use of learning from the 2002 EPA (Environment Agency 2015a),</p>

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		<p>potential gaseous pathways.</p> <p>The descriptive categories used to define the consequence, likelihood and risk ratings for different fault sequences.</p> <p>The selection criteria used to identify appropriate subject and normative experts.</p> <p>Where expert judgement has been used rather than a formal process of expert elicitation.</p>	<p>SDE_005.4 – Accepted / in hand or planned for the 2011 ESC</p> <p>Referencing and quality of data used in the EPA for the 2011 ESC will be addressed as described in the ESC approach document (Baker et al. 2008a).</p>	<p>although we also note that LLW Repository Ltd has concerns with it. The elicited engineering performance values outline the performance range expected during the life of the engineered system (Jackson et al. 2011). However, we consider that potential failure mechanisms and consequences could be more fully assessed and presented or referenced. We will continue to seek improvements in clarity and functionality of the assessment of the performance of the engineered features of the LLWR, for example via a formal EPA (see FI ESC-FI-026).</p> <p>SDE_005.2 - Issue not relevant</p> <p>The concept of engineered features becoming hydrogeologically indistinguishable from the surrounding geology is not a concept considered in the 2011 ESC due to the relatively shortened timescales involved. We note that the heterogeneous nature of Quaternary geology means that hydraulic conductivity of the surrounding geology exhibits a very large range ($1\times 10^{-4} \text{ m s}^{-1}$ to $1\times 10^{-10} \text{ m s}^{-1}$) depending on the lithofacies present adjacent to the engineered liner.</p> <p>SDE_005.3 - Issue not relevant</p> <p>The 2011 ESC used elicited uncertainties as a means of taking account of different future evolution. This approach could, if required be alternately addressed by identifying alternative scenarios either within or outside of an EPA.</p> <p>SDE_005.4 - Issue not relevant</p>

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				<p>A formal EPA has not been carried out to support the 2011 ESC, so that this issue is not directly relevant. However, we have comments on the topics requiring additional information / explanation:</p> <ul style="list-style-type: none"> • The 2011 ESC contained clear and consistent terminology relating to potential gaseous pathways. • Fault sequences were not considered. • The 2011 ESC extensively used expert judgement and elicitation. Experts are identified in project reports, but the mechanism used to select and assess the suitability of the expert either to provide expert opinion or elicitation information is not supplied. This is addressed in Environment Agency (2015a). • The audit trail for decisions made using expert judgement could be improved. <p>We conclude that the transparency of the use of experts and expert elicitation to generate safety and performance values has improved in the 2011 ESC. For future reviews of the ESC, we identified the following areas where the elicitation process would benefit from improvements (Environment Agency 2015a):</p> <ul style="list-style-type: none"> • Improved recording of the information available to experts during the elicitation process • validation of experts competency • further consideration of the use of empirical

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				<p>data where practicable and documentation of any reasoning</p> <ul style="list-style-type: none"> provision of elicitation workshop output reports as part of the ESC package of reports
SDE_006	Engineering Performance Assessment - Derivation of Parameters	<p>SDE_006.1 Provide references to the sources of information used by the experts as the basis for the values elicited for use in the 2002 EPA, and information on how elicited values compare with other information available.</p> <p>SDE_006.2 Conduct systematic sensitivity studies to show the extent to which the hydrological behaviour of the engineered features is sensitive to elicited values for the rate of property changes and the assumptions used for interpolating data between the elicited values.</p> <p>SDE_006.3 Clarify the extent to which the selection of options for engineered features has been based on system-wide assessments rather than on the performance of individual components (see also</p>	<p>SDE_006.1 – Accepted / work complete References for the sources of information are included in the updated EPA (Paksy 2008). SDE_006.2 and SDE_006.3 – Accepted / in hand or planned for the 2011 ESC As noted above, the overall performance of the engineering components will be assessed as part of the 2011 ESC and appropriate sensitivity studies will be undertaken.</p>	<p>SDE_006.1 – Issue carried through to ESC-FI-029 References for the sources of information used in the elicitation process (as reported in Jackson et al. 2011), in particular pre-workshop briefing material, are not clearly presented in the 2011 ESC, although we recognise that they are available elsewhere. It is thus not possible from these reports alone to trace all information used in the elicitation process. We are confident that the elicitation process was carried out in a robust and comprehensive manner providing an appropriate framework for the 2011 ESC assessment. We seek further improvements in this area within ESC-FI-029.</p> <p>SDE_006.2 - Issue carried through to ESC-FI-026 A systematic assessment of the sensitivity of assumed properties of the post-closure engineering on groundwater flow is not presented in the 2011 ESC. Instead, LLW Repository Ltd uses probabilistic and deterministic assessments to model the performance of the engineered barriers with performance assessed at specific timeframes representing key stages in the site evolution. Although broad probability distribution functions</p>

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		SDE_002.4).		<p>were used for the majority of parameters, we would like to see an assessment of the sensitivity of the assessment models to changes in key elicited values resulting from engineering performance failures. This could form part of a future engineering performance assessment as set out in ESC-FI-026.</p> <p>SDE_006.3 – Issue closed</p> <p>The 2011 ESC assessment examined and assessed the performance of engineering systems using a system-wide approach with PDFs elicited for each engineered barrier. We have asked for further development of individual component performance investigation and assessment. This investigation will form part of the LLW Repository Ltd's engineering forward programme (Shaw 2013).</p>
SDE_007	Cap Properties and Behaviour	<p>SDE_007.1 Include an assessment of the implications of not removing the interim cap prior to final cap emplacement in optimisation and risk management studies.</p> <p>SDE_007.2 Instigate field trials of the cap layering system as proposed in DTP/006.</p> <p>SDE_007.3 Provide a justification for the assertion that the layer of</p>	<p>SDE_007.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>The timing of emplacement of the final cap will be considered as part of the optimisation studies on the engineering design.</p> <p>SDE_007.2 and SDE_007.3 – Rejected / disproportionate</p> <p>It is considered that no additional R&D is required for assessment of the final cap performance beyond the work</p>	<p>SDE_007.1 – Issue closed</p> <p>The optimised interim trench cap restoration strategy will incorporate an assessment of the implications of not removing the interim cap prior to the placement of the final (see Environment Agency 2015a).</p> <p>SDE_007.2 - Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>We will require field-based investigation and performance monitoring of the cap system. This is carried through to ESC-FI-001 and ESC-FI-027.</p> <p>SDE_007.3 - Issue carried through to ESC-FI-</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>cobbles in the proposed final cap design will provide an obstruction barrier to burrowing animals and deter roots from penetrating into deeper layers.</p> <p>SDE_007.4</p> <p>Document more clearly the justification for the waste reduction factors used in estimating waste settlement, and instigate a programme of monitoring waste degradation as proposed in DTP/020.</p> <p>SDE_007.5</p> <p>Update the estimates of waste settlement used in the 2002 PCSC to use the latest available information on the inventory, and consider explicitly the potential effects of localised differential settlement.</p>	<p>carried out by Thorne (2008) on cap performance which has indicated that the cap is of robust design and will maintain its core integrity over the lifetime of the facility, even taking into account the effects of erosion and settlement, limiting infiltration into the waste.</p> <p>SDE_007.4 and SDE_007.5 – Accepted / some work done and more planned for the 2011 ESC</p> <p>Thorne (2008) provides details on the estimated settlement of the cap. Justification of the factors used in the calculations will be clarified as part of the 2011 ESC.</p>	<p>027</p> <p>The 2011 ESC incorporates a similar final cap design to that presented in the 2002 PCSC. This includes an anti-intrusion layer comprising of fines-free cobbles. LLW Repository Ltd justifies these designs by comparison to landfill engineering. Although we accept the overall design as being appropriate, we expect to see further confidence building in some elements of the design, using empirical evidence where practicable and beneficial, as part of the cap performance assessment (ESC-FI-027).</p> <p>SDE_007.4 - Issue carried through to ESC-FI-001</p> <p>For the trench disposals, the 2011 ESC built on the 2002 PCSC settlement estimates. These estimates are considered appropriate and robust. However, the settlement predictions cannot take account of the collapse of drums and voids within items because settlement is assessed using the settlement and compression behaviour of homogenous wastes which did not incorporate potentially compressible items such as drums. The proposed placement of a surcharging layer over the trench disposals and engineered fill will mitigate against bulk settlement and uncompacted items and any potential effect on the integrity of the final capping system. This aspect of the recommendation can be closed.</p> <p>An investigation carried out after submission of the 2011 ESC found degradation of some ISO</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
				<p>freight containers within vaults and also ullage within some, suspected to be caused by grout settlement (Jefferies 2012). These findings indicate settlement potential within the containerised waste following capping (see IRF ESC-RI-INF-005). In response, LLW Repository Ltd carried out an extensive investigation into the potential effect of the observed container degradation and voidage (including ullage) on the timing and quantity of settlement (Jefferies 2013, LLW Repository Ltd 2013). We consider that an adequate programme of work is in place to consider these issues and to develop an appropriately engineered final capping system and waste stacking arrangements to accommodate any predicted settlement (as requested under ESC-FI-001).</p> <p>SDE_007.5 - Issue carried through to ESC-FI-001</p> <p>Estimates of trench settlement have been updated in the 2011 ESC. As discussed under SDE_007.4, placement of a surcharging layer provides reassurance that the majority of settlement will have occurred prior to final capping.</p> <p>As discussed under SDE_007.4, a programme of work is in place to address container voidage, degradation and settlement potential.</p>
SDE_008	Derivation and Justification of Radiological	SDE_008.1 Improve the traceability of the reports recording the inventory	SDE_008.1, SDE_008.2, SDE_008.3 and SDE_008.4 – Accepted / substantial work complete and more planned for	<p>SDE_008.1 to SDE_008.5 – Issues closed with recommendations</p> <p>LLW Repository Ltd, as part of the 2011 ESC,</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
	Inventory	<p>derivation work by including detailed cross-references and citations throughout all levels of the PCSC documentation.</p> <p>SDE_008.2</p> <p>Provide access to the Drigg Inventory database, and related Level IV reports and spreadsheets, and include these in future submissions of the PCSC.</p> <p>SDE_008.3</p> <p>Undertake a comprehensive examination of all of the disposal records to extract the maximum possible amount of information on the trench inventory and thereby minimise, and if possible eliminate, the need for backfitting trench inventory estimates from more recent National Inventory estimates.</p> <p>SDE_008.4</p> <p>Modify the Drigg Inventory database to record the activity of each individual radionuclide in the same form as the UK National Inventory.</p> <p>SDE_008.5</p> <p>Provide an assessment of the</p>	<p>the 2011 ESC</p> <p>The work carried out by Wareing et al. (2008) provides a better understanding of the inventory and its derivation taking into account past disposal records, the nature of waste streams and the distribution of radionuclides across the repository. These data will be clearly referenced and available in the 2011 ESC.</p> <p>Further work to interview current and past employees about disposal practices has also been instigated to add confidence to the derived inventory.</p> <p>SDE_008.5 – Accepted / work complete</p> <p>Intrusive investigations are not considered to be feasible due to the large number of boreholes that would be required to have confidence in the predicted inventory as well as the safety issues and cost implications. Ross (2007) considered the potential use of geophysical techniques to characterise the trench waste. The report concluded that</p>	<p>has carried out a substantial amount of work to improve the derivation of the inventory. The derivation has utilised the best available records in this work.</p> <p>For the trenches, LLW Repository Ltd has made use of disposal records, fingerprints, the LLW Tracking System (LLWTS), monthly volume records etc to derive as accurate an inventory as possible.</p> <p>For Vault 8, the LLWTS has been the major source of information.</p> <p>For the forward inventory, LLW Repository Ltd has engaged with consigners to gain a better understanding of the uncertainty associated with key waste streams. It has also identified those streams that will contribute significantly in terms of activity to the key radionuclides inventory within the facility. The revised waste acceptance criteria produced to support the 2011 ESC seek to link the inventory information to the needs of the ESC.</p> <p>Overall, the process carried out by LLW Repository Ltd has led to a more accurate representation of the inventory that will be disposed of to the facility for the radionuclide component. However, there is a significant degree of uncertainty associated with the non-radioactive component of the inventory disposed of and also the forward inventory. We expect LLW Repository Ltd to improve its derivation of the non-radionuclide component and also to address the uncertainty associated with this</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>best practicable means for physical characterisation of the nature and location of trench wastes (for example, geophysical techniques, physical sampling).</p> <p>SDE_008.6</p> <p>Provide an assessment of the feasibility of selective removal from the trenches of wastes that contribute most significantly to risk.</p>	<p>Ground Penetrating Radar, Electromagnetic and Microgravity methods could be used to identifying the volume and shape of the buried materials but that no geophysical method available would provide an accurate depiction of the distribution of Uranium contaminated waste within the trenches. The shielding effect of the trench cap precludes the use of radiometric surveying.</p> <p>SDE_008.6 – Accepted / work in hand</p> <p>A study of the feasibility and cost of selective retrievals that contribute most to assessed post-closure impacts is currently underway. This and will feed into a management options study and thence to the 2011 ESC.</p>	<p>component of the inventory (Recommendations INF10 to INF12). We will work with LLW Repository Ltd going forward to seek to improve the resolution of the inventory and to better describe the full range of non-radioactive waste properties (Environment Agency 2015b).</p> <p>SDE_008.6 – Issue closed</p> <p>LLW Repository Ltd has assessed the feasibility of selective retrievals of trench waste in the optimisation studies supporting the 2011 ESC (LLW Repository 2011).</p> <p>LLW Repository Ltd concluded that no intrusive remediation of the trenches is appropriate because the detriment associated with selective retrievals is judged grossly disproportionate to the benefit. We agree, but consider that the option should be kept open and that LLW Repository Ltd should seek to keep developments in remediation technology under review in a proportionate manner (Environment Agency 2015a).</p>

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8. Appendix 3. CAP IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
CAP_001	FEP Analysis and Engineering Performance Assessment	<p>CAP_001.1 Elicit directly the parameters used in modelling, or seek endorsement from the experts for values derived from their elicited views.</p> <p>CAP_001.2 Provide more detailed justification for the assumptions that some FEPs are considered to be 'subsumed' within the effects of other FEPs or interactions.</p>	<p>CAP_001.1 – Accepted / work complete</p> <p>Thorne (2008) provides a methodology for determining cap performance without the need for elicitation taking into account cap erosion rates and the updated cap design (Belton 2007).</p> <p>CAP_001.2 – In hand or planned for the 2011 ESC</p> <p>A simplified approach to FEP management is proposed for the 2011 ESC, see section 5.3.3 of the 'Approach to 2011 ESC' (Baker et al. 2008).</p>	<p>CAP_001.1 - Issue carried through to ESC-FI-001, ESC-FI-027 and ESC-FI-029</p> <p>LLW Repository Ltd used elicited values for cap infiltration performance in the 2011 ESC (from Jackson et al. 2011). The values presented are considered robust and take account of the performance information available. This aspect of the recommendation can be closed.</p> <p>The 2011 ESC presented an engineering design based on engineering best practice, optimisation studies and performance requirements.</p> <p>Because the final cap design is at a relatively conceptual stage (in other words further detailed design is required prior to construction) we consider it possible that the range of elicited performance values will differ from those in the as-built final cap. Appropriate revisions should therefore be made to the elicited values presented and used in the 2011 ESC (Jackson et al. 2011), to take account of changes to the design that occur during the design substantiation and development process. These requirements are covered in ESC-FI-001, ESC-FI-027 and ESC-FI-029.</p> <p>CAP_001.2 - Issue not relevant</p> <p>The 2011 ESC includes a new FEP and uncertainty tracking system (LLW Repository Ltd 2013a), thus this recommendation is no longer</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				relevant. LLW Repository Ltd used this system to map the changes to the FEPs between the 2002 PCSC and the 2011 ESC. Comments on the treatment of engineering FEPs and uncertainty in the 2011 ESC are provided in Environment Agency (2015a).
CAP_002	Cap Integrity and Performance – Groundwater Pathway	<p>CAP_002.1</p> <p>Assess the importance of cap infiltration to calculations of dose via the groundwater pathway, and consequently adopt either a simplified approach to defining infiltration or adopt a more detailed cap profile in future hydrogeological modelling.</p> <p>CAP_002.2</p> <p>Adopt a set of assumptions regarding the settlement and erosion of the cap that are consistent throughout all parts of the PCSC or that are demonstrably cautious for each pathway considered. Provide better justification for assumptions regarding changes in the cap topography in response to settlement (see also SDE_007.5). Justify the rate of cap erosion assumed.</p>	<p>CAP_002.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>The influence of cap design on the safety assessment will be considered as part of the 2011 ESC. Thorne (2008) defines how infiltration rates are calculated for the proposed cap design. It is not proposed to model the cap in detail within the site-scale model.</p> <p>CAP_002.2</p> <p>Thorne (2008) addresses the issue of cap settlement. If the intention to ensure that any assumptions made in the determining performance of the cap will be consistent with the performance of other engineered components in the 2011 ESC.</p>	<p>CAP_002.1 - Issue carried through to ESC-FI-001, ESC-FI-023 and ESC-FI-027</p> <p>The final cap is identified as a control measure, whose function is to minimise infiltration into the wastes amongst others. Elicitation was used to generate infiltration properties of the cap over the life of the LLWR (Jackson et al. 2011). These values were derived as probability distribution functions. The assessment used current engineering good practice information on knowledge of the degradation and failure of geosynthetic components.</p> <p>The performance of the cap controls infiltration changes over the life of the repository. At the point of construction the capping system is assumed to perform to near 100% efficiency, with a gradual decrease in the performance of the engineered cap components with time. During the period of authorisation, infiltration through the cap is expected to be low. At an undetermined time, the rate of infiltration may exceed the rate of leakage through the base. If this occurs, leachate is designed to overtop the 1 m side liner and enter the adjacent shallow geologies and basal drainage system to allow effective dispersion of leachate at a rate greater</p>

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				<p>than the predicted inflow. This design feature is not present in Vault 8 and the current Vault 9; here, leachate will flow to the adjacent Vault 9A or 10 prior to discharge via the 1 m side liner (subject to final detailed design decisions). LLW Repository Ltd has demonstrated that the optimised design features will prevent overtopping of leachate to the surface environment and adjacent surface water pathways. Vault 9 has been constructed to allow the incorporation of sufficient basal drainage capacity in the adjacent Vault 9a and to allow future engineering of flow paths from one Vault 9 to 9A.</p> <p>The optimised basal drainage system will be implemented for future vaults; it has not been fully incorporated into the Vault 9 design and is not present in Vault 8 which was built to an earlier design. We have sought further evidence from LLW Repository Ltd that Vault 8 and 9 (and adjacent trenches) can effectively disperse leachate to the under liner drainage system via ESC-FI-023, if necessary following engineering modifications.</p> <p>During the period of authorisation, LLW Repository Ltd will manage leachate levels within the vaults, thereby decoupling the cap performance from basal discharge (LLW Repository Ltd 2015b).</p> <p>As the cap degrades, the HER will have an increasing influence on the rate of infiltration into the waste mass. The rate of discharge via either</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				<p>the vault base or the engineered basal drainage layer will depend on the HER and extent of cap degradation.</p> <p>The expected reduction of cap engineering performance is likely to occur over a similar timeframe to the disruption of the site by coastal erosion.</p> <p>For the extended timeframes associated with the delayed coastal erosion and the no erosion scenarios we consider that LLW Repository Ltd has carried out appropriate assessments for the degraded engineered cap.</p> <p>However, we consider that the 2011 ESC could have examined the performance of the cap in further detail. The main cap degradation mechanism is identified as settlement. There is no discussion on the effect, and significance, of potential cap failure mechanisms associated with waste settlement, although the elicited infiltration range is intended to encompass these mechanisms. LLW Repository Ltd has instigated a programme of work to examine settlement potential and impacts upon the cap. Our expectations for additional performance assessment are carried forward via ESC-FI-001 and ESC-FI-027.</p> <p>CAP_002.2 - Issue carried through to ESC-FI-001</p> <p>As discussed under CAP_002.1, the 2011 ESC does not model the performance of the cap in detail, nor present assessments of the effect,</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				<p>and significance, of potential cap failure mechanisms associated with waste settlement.</p> <p>During ISO freight container inspections completed by LLW Repository Ltd to assess container condition, it was observed that some of the ISO freight containers of waste in Vault 8 were in a poor condition. Penetrative corrosion of container lids and walls was observed along with 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 (Jefferies 2012 and 2013; LLW Repository Ltd 2013b). These issues will have an effect on settlement of 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, which we consider adequate. Initial progress is described in Jefferies (2013) and reviewed in Environment Agency (2015b). Our requirements for this work are taken forward through ESC-FI-001.</p>
CAP_003	Cap Integrity and Performance – Gas Pathway	<p>CAP_003.1</p> <p>Consider calculations to scope the effect of a house constructed over a gas vent, or over a fissure. Justify why Rn-220 is never assessed (even when the cap is thin).</p>	<p>CAP_003.1 – In hand or planned for the 2011 ESC</p> <p>Consideration of gas migration was considered as part of the Schedule 9 Requirement 2 submission (Sumerling 2008), which has increased our confidence in the assessment</p>	<p>CAP_003.1 - Issue closed</p> <p>The 2011 ESC includes an assessment of radiation doses to occupants of a house that penetrates the gas collection layer and after the failure of the low permeability capping layers and thus addresses this recommendation.</p> <p>CAP_003.2 - Issue closed</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		CAP_003.2 Assess the implications of the migration of bulk gas (including entrainment of radon).	<p>of radon from Ra-226 disposals. Further calculations are currently being undertaken and will be considered as part of the 2011 ESC.</p> <p>CAP_003.2 – Accepted / work complete or in hand and to be presented in the 2011 ESC</p> <p>Gas bulk migration was considered by Ball et al. (2008). Calculations in (Sumerling 2008) show the effect is to be small. More recent work has confirmed this and identified atmospheric pressure variations probably the main driver for gas migration in the wastes and cap.</p>	<p>The 2011 ESC includes an assessment of the implications of the migration of bulk gas. In support of the 2011 ESC we sought further information from LLW Repository Ltd to substantiate the chosen management approach with regard to gas composition, generation time, flow potential and generation rate of gas.</p> <p>Following provision of further information and clarifications we are confident that the 2011 ESC assessment does provide an appropriate assessment of the radiological safety consequences of bulk gas generation. Therefore this issue can be closed.</p> <p>We note that the final engineered cap design details for gas management have not been defined at this stage. We will seek appropriate detailed designs and design substantiation during the development of the engineered cap. This is carried forward through ESC-FI-024.</p>
CAP_004	Cap Integrity and Performance – Intrusion Pathway	CAP_004.1 Justify the selected erosion rates and erosion model used to determine consequences of intrusion.	<p>CAP_004.1 – Work undertaken / No longer relevant</p> <p>As noted under CAP_001, further work has been carried to assess the erosion rates of the cap (Thorne 2008).</p> <p>Human intrusion scenarios for the 2011 ESC are being reconsidered, (see section 2.5, Disruptive events). The reduced time to expected disruption of the site by coastal</p>	<p>CAP_004.1 - Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>We accept that bulk erosion of the cap resulting in the removal of a substantial thickness of cover material is unlikely to occur before site disruption is projected. We thus do not consider large scale reduction of the thickness of the engineered cap to be a valid failure mechanism.</p> <p>Although we consider the issue of bulk erosion to have been adequately addressed, we wish to see further consideration of the effect of localised erosion on the integrity and robustness</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
			erosion means there is no longer a significant influence of assumed natural erosion rates on human intrusion scenarios.	of the engineered cap. We have asked LLW Repository Ltd to identify and assess localised cap erosion mechanisms in ESC-FI-001 and ESC-FI-027.
CAP_005	HELP Modelling	<p>CAP_005.1 Undertake a more comprehensive set of sensitivity / uncertainty analyses for the cap to explore more fully the potential range of infiltration through the cap and the effect of changing infiltration on the source term for radionuclide transport via all pathways.</p> <p>CAP_005.2 Explain the apparent differences between water balance and infiltration through the cap calculated using different approaches, and justify the selected approach.</p>	<p>CAP_005.1 – Accepted / In hand or planned for the 2011 ESC</p> <p>The sensitivity of the safety assessment to cap design will be considered as part of the 2011 ESC using the potential range of infiltration through the cap.</p> <p>CAP_005.2 – Accepted / In hand or planned for the 2011 ESC</p> <p>Infiltration through the interim cap is being assessed as part of the response to Schedule 9 Requirement 7. Different approaches are being used to provide checks that the values selected are justifiable.</p>	<p>CAP_005.1 - Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>The 2011 ESC includes elicited infiltration values over the life of the site (Jackson et al. 2011). These values were presented on a probability basis.</p> <p>We consider that the range of infiltration values presented is valid and robust. However, although the elicited infiltration values took account of potential localised failures in the capping system associated with any localised differential settlement, this information was not presented in the 2011 ESC. We also consider that the ESC and the elicited cap infiltration values would benefit from a fuller understanding of potential localised cap failures and their effect on the predicted infiltration rates. We set out our expectations in ESC-FI-001 and ESC-FI-027.</p> <p>CAP_005.2 – Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>LLW Repository Ltd has carried out extensive investigations into the performance of the interim trench cap as part of its annual reporting under Schedule 9 Requirement 7 of the current permit (for example, LLW Repository Ltd 2011a). These investigations have identified a significant difference between predicted cap performance</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				<p>and measured cap performance. We asked LLW Repository Ltd to quantify the significance of this difference in IRF ESC-TQ-INF-018 and an adequate response was provided.</p> <p>As a result of a subsequent BAT study to assess options for improving the performance of the interim cap (Paulley et al. 2012) LLW Repository Ltd implemented a programme of repairs that is designed to reduce infiltration through the interim trench cap. During the repair work, additional failures within the cap were identified. At the time of writing LLW Repository Ltd is reassessing its strategy for making the necessary improvements. We will continue to require LLW Repository Ltd to implement the BAT for the management of the interim trench cap prior to installation of the final cap.</p> <p>We require LLW Repository Ltd to put in place appropriate monitoring to assess any changes to the performance of the trench cap. This issue is being taken forward through ESC-FI-001 and ESC-FI-027.</p>

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9. Appendix 4. NRF IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
NRF_001	Nuclear criticality	<p>NRF_001.1 Account in the Drigg post-closure criticality safety case for the uncertainty in the inventory of fissile isotopes.</p> <p>NRF_001.2 Demonstrate how criticality safety arguments will apply in the event of changes to the limit on the uranium content of waste containers.</p>	<p>NRF_001.1 / 1.2 – Accepted / In hand or planned for the 2011 ESC</p> <p>We will include a short re-evaluation of the potential for nuclear criticality as part of the 2011 ESC. In the re-evaluation, we will discuss uncertainties and the implications of waste acceptance criteria and container limits. We do not propose a major activity since the content of fissile material is so low that the chance of a criticality is remote.</p>	<p>NRF 001.1 – Issue closed LLW Repository Ltd has produced distribution maps of the location of plutonium within the trenches that demonstrates the heterogeneity of the materials (Lennon et al. 2011). In addition, it has carried out an assessment of the plutonium inventory within the trenches and has presented a case that the uncertainty in the inventory is plus or minus an order of magnitude (Baston et al. 2011). This has subsequently been fed into the criticality assessment (Putley et al. 2011). From the information presented, we agree with the conclusion that the risk from criticality is low.</p> <p>NRF 001.2 - Issue closed The LLWR WAC include limits for fissile material for individual consignments (LLW Repository Ltd 2011a). Consignments exceeding these limits would only be accepted after a further assessment showed that it was safe. We are satisfied that no consignments above the limits at present will be accepted into the facility without proper review.</p>
NRF_002	Supply of near-field information	NRF_002.1 Adopt a more inclusive approach when developing future updates of the PCSC that allows the regulator to comment on actual drafts of the safety case	NRF_002 all parts – Accepted / In hand or planned for the 2011 ESC / We are committed to as much exchange of information and review as possible, consistent with	<p>NRF_002.1, NRF 002.2 and NRF 002.3 - Issues closed with recommendation We carried out regular liaison with LLW Repository Ltd during development of the 2011 ESC. This led to an improvement on the 2002 PCSC development process. Documents and</p>

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		<p>documents, including results from performance assessment calculations, as they are developed during the conduct of successive iterations of safety assessment.</p> <p>NRF_002.2</p> <p>Provide information readily and in a timely manner and strive to achieve the highest levels of openness and transparency.</p> <p>NRF_002.3</p> <p>Plan the production of the safety case documentation in a strategic manner such that it facilitates regulatory review and stakeholder dialogue.</p> <p>NRF_002.4</p> <p>Respond to each of the issues raised by the Agency following the Agency's Issue Resolution Procedure.</p>	<p>project timescales</p> <p>LLW Repository Ltd wishes to adopt an open approach and to make documents available for regulatory comment in a regular and timely manner. For example, we have recently provided the Safety Case Approach Document to the Environment Agency and will provide other interim documents before the 2011 ESC. However, we do not wish to commit to produce early drafts of Safety Case documentation for review as project timescales might make this difficult. We suggest that such opportunities for review and exchange of information should continue to be discussed at the regular liaison meetings between LLW Repository Ltd and the EA.</p> <p>We have previously responded to the IAFs provided by the Environment Agency. This document provides a further review.</p>	<p>relevant information required during the review was supplied in a timely manner.</p> <p>We consider that information in the Level 2 documents could be better traced back to the supporting Level 3 documents. We also recommend that, to improve clarity and the efficiency of review, future ESC submissions should aim, as far as possible, to include all relevant information to 'make the case' without the need for us to request further information (Recommendation SCM5). Also see COR_024.</p> <p>NRF_002.4 - Issue closed</p> <p>LLW Repository Ltd has followed the due procedure for dealing with IAFs.</p>
NRF_003	Near-field disaggregation	<p>NRF_003.1</p> <p>Re-assess the structure of the Drigg PCSC documentation and</p>	<p>NRF_003.1 – Accepted / In hand or planned for the 2011 ESC</p>	<p>NRF_003.1 – Issue closed with recommendation</p> <p>The structure of the 2011 ESC is an</p>

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		aim for greater levels of transparency in future revisions to the Drigg PCSC.	The structure of the 2011 ESC documentation will be improved from that in the 2002 PCSC and is discussed in the Safety Case Approach Document (Baker et al. 2008).	<p>improvement over the 2002 PCSC, providing greater clarity and traceability of information and assumptions in the documents and as used in the models. A limited number of key Level 3 near field documents were included in the 2011 ESC as submitted. We requested further underpinning information on a number of topics such as colloids and uranium.</p> <p>To improve clarity and the efficiency of review, we recommend that LLW Repository Ltd ensures that documents submitted in the next update to the ESC provide, as far as possible, all relevant information to 'make the case' without the need for us to request further information (Recommendation SCM5).</p>
NRF_004	Near-field FEP screening	<p>NRF_004.1 Provide traceable documentation demonstrating a systematic analysis of the FEPs that may influence the site, including the use of reasoned arguments and scoping calculations for extreme events and for processes not otherwise considered in the PCRSA.</p> <p>NRF_004.2 Provide traceable documentation of the reasoning for the elimination of FEPs from the assessment calculations on the basis of well-defined</p>	<p>NRF_004 all parts – Accepted, although our proposed review and re-analysis will be more limited in scope than undertaken for the 2002 PCSC / In hand or planned for the 2011 ESC</p> <p>As part of the 2011 ESC, we propose to review the list of relevant FEPs and to provide an audit of their treatment or exclusion. Such treatment might involve addressing a FEP within an assessment model or conducting some side calculation to justify a view that further consideration of the</p>	<p>NRF_004.1 and NRF_004.2 – Issues closed LLW Repository Ltd's FEP and uncertainty tracking system provides an auditable trail of the uncertainties within the 2011 ESC, their importance and how they have been addressed within the ESC (LLW Repository Ltd 2013). Details of the generation of the FEP list and the development of the tracking system are provided in Lean and Willans (2010) and Lean and Lennon (2010). Thus this issue has been closed.</p> <p>NRF_004.3 to NRF_004.6 – Issues closed The major uncertainties associated with the near field are identified in the FEP and uncertainty tracking system (LLW Repository Ltd 2013). This provides evidence that LLW Repository Ltd is aware of key uncertainties and has provided an</p>

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		<p>elimination (screening) criteria. NRF_004.3</p> <p>Provide traceable documentation of the treatment of FEPs in the assessment calculations. NRF_004.4</p> <p>Document FEPs and models in a way that reduces uncertainty in the inclusion or exclusion of FEPs in PCRSA models. Where possible, relate FEPs directly to the terms in the mathematical equations solved by the assessment codes. Where FEPs are incorporated in the PCRSA calculations through parameter values, document the relationship between the parameter values and the FEPs contributing to the selected values of those parameters. Where FEPs are included in the PCRSA through the way in which the PCRSA models are used to simulate particular scenarios, explain clearly how such FEPs are incorporated in the PCRSA analysis. NRF_004.5</p> <p>Demonstrate consistency</p>	<p>FEP is not required.</p>	<p>audit trail showing how their potential effect on the 2011 ESC was assessed.</p>

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		<p>between assessment models and computer codes, and the results of the systematic analysis of FEPs.</p> <p>NRF_004.6</p> <p>Provide traceable documentation of any situations in which the limitations of the assessment codes, or inconsistencies between the assessment codes and the results of systematic analysis of FEPs, may bias assessment results.</p>		
NRF_005	Near-field model description, assumptions and justification	<p>NRF_005.1</p> <p>Review the assumptions that underlie the DRINK model (particularly those associated with the range of metals considered, the corrosion model, and the sorption model for the trenches) and modify the model so that it is more closely representative of the actual wastes at the disposal facility, and can be used on a more routine basis to consider the post-closure impacts of site operations and the acceptability of specific waste consignments.</p>	<p>NRF_005.1 – Partially accepted / In hand or planned for the 2011 ESC</p> <p>This comment is in part superseded since LLW Repository Ltd does not intend DRINK to fulfil the same role in the assessment modelling as was the case in the 2002 PCSC. In the 2011 ESC, DRINK will be used as a supporting tool to support a simpler assessment model. We will consider modifications and updates to the model prior to its use in the 2011 ESC. However, we do not see DRINK as the regular choice of</p>	<p>NRF_005.1 - Issue closed</p> <p>LLW Repository Ltd has used output from the GRM near field model in the 2011 ESC in a very different way from output from DRINK in the 2002 PCSC. GRM is used to gain an understanding of how the near field will develop. However, only data for C-14 are taken directly from the GRM as input into the assessment calculations. The majority of C-14 will be associated with mild steel components, concrete and graphite from reactor decommissioning. The dominant waste is metals, in particular, steels. Uncertainties associated with corrosion rates for a number of metals have been elicited and are taken into account in the 2011 ESC. We consider that this issue is closed, although we raised a related IRF requiring further assessment of impacts associated with C-14 via</p>

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			software tool to address the issues identified in the recommendation.	the gas pathway, which will be dependent on the degree of corrosion within the near field (IRF ESC-RI-ASO-005). LLW Repository Ltd's response to this RI addressed our queries and we have closed it.
NRF_006	Near-Field Model Implementation	<p>NRF_006.1 Provide results from calculations to evaluate the uncertainty introduced to the near-field modelling results by the scale of spatial discretisation of the waste in the DRINK model.</p> <p>NRF_006.2 Provide results from calculations to evaluate the uncertainty introduced to the near-field modelling results by the selection of time steps in DRINK calculations.</p>	<p>NRF_006.1 / 6.2 – Partially accepted / In hand or planned for the 2011 ESC</p> <p>We will consider the need to evaluate such numerical effects when reviewing the further use of DRINK. This is a task that will begin shortly.</p>	<p>NRF 006.1 - Issue carried through to ESC-FI-016</p> <p>LLW Repository Ltd has improved the discretisation within the GRM used in the 2011 ESC for both the trenches and the vaults. We note that the grid size for GRM is discretised to a greater extent than that presented within the PCSC 2002 (LLW Repository Ltd, 2011b). However, it is not clear how LLW Repository Ltd has demonstrated the sensitivity of GRM to changes in discretisation. This is particularly important for C-14 as GRM output is used as direct input to the assessment calculations. We expect to see a direct comparison between grid sizes for a specific variable to demonstrate that the grid size effects are within acceptable limits. We note that LLW Repository Ltd has begun to assess the effect of heterogeneity of the waste on the results generated from the GRM. This is still ongoing for the vaults, as Vault 8 is only partly filled and the effect of higher stacking should be assessed. In addition, the effects of heterogeneity between vaults have not been fully assessed as there are currently no disposals to Vault 9. This should be considered further in the next iteration of the ESC (ESC-FI-016).</p> <p>Computer power and the running time of the</p>

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				<p>model are critical to answering this question; the degree of discretisation is limited by the ability to run the model for a reasonable time. However, we note that potentially smaller sections of the model could be run to assess whether the discretisation might have any significant effect on the model output.</p> <p>NRF_006.2 – Issue closed with recommendation</p> <p>Small et al. (2011a) has carried out a study to assess the optimum time step for GRM. This study assessed time steps of 0.01 years and 0.05 years. 0.05 years was found to provide the optimum time step. However, we note that the report states that further refinement of the time steps may occur as a result of further refinement of the model and also where different flow models are considered. Thus we recommend that the recommendations of Small et al. (2011a) are considered in future use of GRM (or alternative near field models) and that, in further refinement of the model, LLW Repository Ltd assesses whether the time step for the GRM is still optimum (Recommendation INF15).</p>
NRF_007	Near-field parameters	<p>NRF_007.1 Document and justify the parameter values used in the PCSC.</p> <p>NRF_007.2 Document the primary sources of data used in establishing the</p>	<p>NRF_007.1 / 7.2 / 7.3 / 7.5 – Accepted / in hand or planned for the 2011 ESC</p> <p>LLW Repository Ltd will implement a data control procedure that require the documentation of parameter values, the sources of data and</p>	<p>NRF_007.1 to NRF_007.5 – Issues closed</p> <p>LLW Repository Ltd set up a data management system for data used in the 2011 ESC but did not use it widely as a means of documenting and substantiating parameter values and controlling data usage (Cummings 2010). Although all data used in assessment calculations and in key supporting calculations are covered by this</p>

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		<p>parameter values used in the PCSC.</p> <p>NRF_007.3</p> <p>Document the calculations and techniques used to derive parameter values from primary data.</p> <p>NRF_007.4</p> <p>Document the range of uncertainty associated with the parameter values used in the PCSC.</p> <p>NRF_007.5</p> <p>Document which features, events and processes are represented within each range of parameter values.</p> <p>NRF_007.6</p> <p>Demonstrate that the thermodynamic database used in the PCRSA calculations is internally-consistent and has been compiled using appropriate procedures.</p>	<p>any related assumptions.</p> <p>NRF_007.4</p> <p>In characterising uncertainty we propose to focus on those parameters that are significant in terms of performance. We will justify which parameters are important as part of the analysis.</p> <p>NRF_007.6 – Rejected</p> <p>We propose to use the best available thermodynamic data. However, it needs to be recognised that available thermodynamic databases are not fully consistent internally.</p>	<p>procedure, a lot of data were excluded from the process, for example if they were only used in one model. Thus not all near field parameter values are captured in this system.</p> <p>Instead, Kelly et al. (2011) provides information on the parameters used in the groundwater assessment, in particular those relating to sorption coefficients and the inventory. In addition, GRM documentation provides information detailing the parameters critical to the near field such as inventory, model discretisation, chemical species using PHREEQ and flow models (Section 5 of Small et al. 2009; Section 3 of Small et al. 2011a and Section 2 of Small et al. 2011b). Details are provided on how each of the parameters used within GRM are formulated and applied to GRM.</p> <p>Uncertainty, particularly for the groundwater pathway, has been dealt with through elicitation and use of variant cases to model extremes such as the higher inventory etc. GRM has also been used to look at a number of uncertainties such as cellulose degradation rates, grout contents etc. Thus the information presented within the documents supplied provides the relevant information to address this IAF.</p> <p>NRF 007.6 – Issue closed</p> <p>Small et al. (2009) describe how the thermodynamic database has been derived. It is derived from the Hatches v18 database, which is maintained and updated by Radioactive Waste Management (RWM). We consider this a</p>

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				suitable approach.
NRF_008	Near-field Performance and uncertainties	<p>NRF_008.1 Revise its approach to the treatment of uncertainty in the Drigg PCSC, and base future PCSCs for Drigg on probabilistic safety assessment calculations.</p> <p>NRF_008.2 Conduct a thorough quantitative uncertainty analysis to evaluate uncertainties associated with the selection of conceptual models, modelling assumptions and parameter values, and present a justification for the adopted approach.</p> <p>NRF_008.3 Conduct multi-parameter sensitivity analyses to help prioritise work aimed at reducing uncertainties, and present a justification for the adopted approach.</p>	<p>NRF_008.1 – Accepted / In hand or planned for the 2011 ESC We propose to undertake a probabilistic safety assessment for the groundwater pathway.</p> <p>NRF_008.2 – Accepted / In hand or planned for the 2011 ESC Our overall approach to dealing with uncertainty is set out in the Safety Case Approach Document (Baker et al. 2008). We will put the available effort into characterising the uncertainty in key parameters.</p> <p>NRF_008.3 – Accepted / In hand or planned for the 2011 ESC Sensitivity analyses for key parameters will be an important part of our approach.</p>	<p>NRF_008.1 — Issue closed LLW Repository Ltd carried out a probabilistic assessment of the groundwater pathway and this is reported in Section 7 of Kelly et al. (2011). LLW Repository Ltd assessed a number of variant cases, including one probabilistic case, which covers the concerns raised in this IAF relating to variation of near field parameters. We note that LLW Repository Ltd has also carried out a number of deterministic cases covering a wide range of parameters such as adsorption and solubility that will have an effect on the groundwater assessment. Thus this issue is closed.</p> <p>NRF_008.2 – Issue closed LLW Repository Ltd carried out a number of variant cases in the groundwater assessment to assess the sensitivity of the models used in the 2011 ESC to various parameters. The company demonstrated that it has identified the key parameters within the models that could have a significant effect on the 2011 ESC. Calculations have been carried out to assess the effects of varying a number of geological and chemical parameters on the model output. We are satisfied that the work carried out within the 2011 ESC addressed our concerns raised in this IAF.</p> <p>NRF_008.3 – Issue carried through to ESC-FI-008 The use of a probabilistic calculation case for the</p>

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				<p>groundwater pathway is an improvement over the 2002 PCSC, which did not make use of probabilistic methods (Kelly et al. 2011). LLW Repository Ltd also assessed a number of deterministic variant cases looking at the effect of uncertainties on the risk associated with the groundwater pathway. However, these cases do not take into account the effects of multi-parameter uncertainty. This issue was raised in IRF ESC-TQ-INF-026 with respect to assessment of the combined effects of reduced adsorption and increased solubility, which are two important parameters for uranium and the near field. In response, LLW Repository Ltd assessed a combined variant case that addressed this specific issue.</p> <p>Uncertainty in FEPs and associated parameter values is reviewed in the FEP and uncertainty tracking system (LLW Repository Ltd, 2013). Areas of work to address some significant uncertainties going forward are highlighted. We support this work and recommend that this should be continued for future iterations of the ESC (FI ESC-FI-008). However, it appears that if LLW Repository Ltd is content with the treatment of a particular FEP in the 2011 ESC, then no proposals for further assessment of whether the uncertainties can be reduced are provided, even where these uncertainties are considered high and/or with the potential to affect the ESC. Examples include FEPs on 'release from waste form – metals' (near field trenches and vaults) and 'effects of site engineering' (groundwater</p>

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				<p>pathway – contaminant migration).</p> <p>We require LLW Repository Ltd to reduce key uncertainties where practicable and beneficial to do so, including those for the near field and focusing on those uncertainties that are considered to have the potential to affect the ESC significantly (ESC-FI-008).</p> <p>We have also noted some inconsistencies in the classification of uncertainties in similar FEPs, which is discussed in Environment Agency (2015).</p>
NRF_009	Near-field flow	<p>NRF_009.1 Demonstrate clearly that the post-closure risk assessment adequately accounts for the potential effects of gas flow and pressurisation on repository components (for example, the cap).</p> <p>NRF_009.2 Provide evidence to build confidence in the hydraulic conductivities selected for the below-ground structures.</p> <p>NRF_009.3 Conduct a sensitivity analysis to evaluate the effect of the</p>	<p>NRF_009.1 – Mainly accepted / Work is in hand or planned for the 2011 ESC</p> <p>We do not think it is feasible that the repository as a whole could become pressurised to any significant extent. Gas vents will be present which will prevent pressurisation, noting that gas is dominantly generated during the period of management control. The effects of gas flow on radiological impacts, from radon and C-14-labelled species will be evaluated.</p> <p>NRF_009.2 – Mainly accepted / Work is in hand or planned for the 2011 ESC</p> <p>Where possible, we will provide</p>	<p>NRF_009.1 – Issue closed LLW Repository Ltd provided information on gas generation rates for gases such as carbon dioxide (CO_2) and methane (CH_4) in the 2011 ESC. This suggests that the flow rates from the LLWR are liable to be between 3 to 7 m^3/hr. We agree with LLW Repository Ltd that the cap should be able to manage such low flows and would not require an additional gas management programme as a result of gas generation rates. We ask LLW Repository Ltd to develop a gas management strategy in FI ESC-FI-024. We would expect the gas management strategy to ensure that gas pressurisation does not occur before or after the period of authorisation.</p> <p>NRF 009.2 Issue carried through to ESC-FI-026 The long-term performance of the engineered barriers was elicited by a group of experts (Jackson et al. 2011). Although we accept that</p>

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		<p>timescale over which the near-field is assumed to degrade.</p> <p>NRF_009.4 Document a quantitative assessment of the potential consequences of repository flooding.</p>	<p>evidence and arguments in support of the properties assigned to degraded engineered barriers. However, it should be recognised that there is an element of judgment in such assignment.</p> <p>NRF_009.3 – Mainly accepted / Work is in hand or planned for the 2011 ESC</p> <p>The variation of groundwater flow through the repository is an important control on performance and the implications of uncertainty will therefore be evaluated by the proposed probabilistic calculations.</p> <p>NRF_009.4 – Mainly accepted / Work is in hand or planned for the 2011 ESC</p> <p>The consequences of bathtubning leading to localised discharges will be assessed in the 2011 ESC.</p>	<p>this approach can generate robust long-term performance values, we questioned the lack of supporting research information, both site specific and generic. LLW Repository Ltd is developing an engineering forward programme, in which we wish to see development of more site-specific barrier performance values where practicable (Shaw, 2013). This expectation is outlined in ESC-FI-026.</p> <p>NRF 009.3 – Issue closed</p> <p>LLW Repository Ltd carried out a sensitivity analysis of the effect of the timescale over which the near field is assumed to degrade. Small et al. (2011a) assess variant cases looking at greater infiltration rates into the near field and subsequent degradation of the near field. This includes assessment of effects on uranium and the Eh and pH of the facility. We consider that this issue has been adequately addressed.</p> <p>NRF 009.4 – Issue carried through to FI ESC-FI-023</p> <p>The repository design concept has changed since 2002. The 2011 ESC vault design incorporated a 1 m side liner above which leachate will be diverted into the adjacent geologies after the degradation of the capping system. It is therefore important that vault leachate levels can be maintained below the level of the side liner. In ESC-FI-023 we have requested that, as part of the engineering forward programme, a full assessment of the flooding of the vaults is completed, particularly</p>

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				<p>for Vault 8. This response will form part of a leachate management strategy.</p> <p>NRF_009.4 specially refers to a quantitative assessment of the potential consequences of potential repository flooding. The assessment of the flood risk of the LLWR at a repository scale will be addressed as part of a planning application and is outside of the scope of our assessment of the 2011 ESC. Our review did cover the need to minimise and control vault leachate levels during the period of authorisation.</p>
NRF_010	Near-Field Colloids and Organic Complexation	<p>NRF_010.1 Undertake further applied research to reduce uncertainties related to colloids, including kinetically-controlled radionuclide sorption on colloids, and colloid stability; and develop a scientifically justified assessment of the potential influence of colloids on radionuclide mobility, dose and risk.</p> <p>NRF_010.2 Evaluate the potential significance of organic complexation to radionuclide mobility, dose and risk in the Drigg disposal system.</p>	<p>NRF_010.1 – Rejected / disproportionate Our view of colloids is addressed under GEO_004. We propose to address the issues in the ESC, but do not regard the area as a priority for further research. We do not feel that the areas identified by NRF_010.1 are the most significant potential impacts as far as colloids are concerned.</p> <p>NRF_010.2 – Accepted / work completed We will present arguments in the 2011 ESC in relation to the significance of organic complexation, which we consider to be of low impact,</p>	<p>NRF_010.1 – Issue carried through to ESC-FI-015 LLW Repository Ltd carried out a cautious sensitivity analysis to assess the effect of adsorption within the groundwater pathway assessment. Calculation R12 of Kelly et al. (2011) demonstrated by modelling that in the unlikely situation of zero adsorption within the facility the risk guidance level would only just be exceeded. LLW Repository Ltd states that this is a very cautious extreme case and we agree.</p> <p>IRF ESC-TQ-INF-026 queries the use of these variant cases in particular with relation to uranium. This TQ questions why the variant cases of solubility and adsorption were kept separate and why LLW Repository Ltd did not assess the effect of combined solubility and adsorption variant cases. In response, LLW Repository Ltd assessed a combined variant</p>

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			as demonstrated by work subsequent to the 2002 PCSC (Trivedi et al. 2008).	<p>case that addressed this specific issue. LLW Repository Ltd also produced a number of technical reports on colloids addressing irreversible adsorption and LLW Repository Ltd's understanding of this phenomenon at the LLWR. We agree that further R&D in this specific area may not be an area for priority research, but we consider that LLW Repository Ltd should ensure that a technology watch is maintained on developments on the understanding of the effects of colloids on radionuclide adsorption. We also consider that periodic and proportionate sampling for colloids should be carried out to further assess whether colloids do present a risk to the environment (see GEO_003.8). This is being taken forward via ESC-FI-015.</p> <p>NRF_010.2 – Issue carried through to ESC-FI-009</p> <p>As discussed above, in the unlikely situation of zero adsorption within the facility the risk guidance level would only just be exceeded (Kelly et al. 2011). However, no assessment of the implications of increased solubility in conjunction with zero adsorption has been carried out, although this is also an extreme case. This issue has been raised in IRF ESC-TQ-INF-026 (see NRF_012.1).</p> <p>LLW Repository Ltd carried out a review of the superplasticiser Sikament-10 and its potential for chelating radionuclides. Although we consider that this issue has been adequately addressed in the 2011 ESC, LLW Repository Ltd should</p>

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				ensure that an adequate monitoring programme is in place to ensure that potential complexants in leachate are identified and assess the potential implications on radionuclide migration. This issue is being taken forward via ESC-FI-009.
NRF_011	Near-Field Microbes	<p>NRF_011.1 Provide further justification for the selected value of the initial microbe concentration parameter, or document evidence to support the assertion that the value of the parameter is of low significance to the performance of the disposal system.</p> <p>NRF_011.2 Provide further information on the sensitivity analyses conducted to assess the significance of the microbiological parameters and modelling assumptions, fully document the rationale behind the decisions to perform the sensitivity analyses, and document in a clear and transparent manner the links between the significance indices on the microbiological Parameter Input Forms and the results from the sensitivity</p>	<p>NRF_011.1 / 11.2 – No longer relevant or rejected</p> <p>Our approach to modelling gas release in the 2011 ESC is under development. We will examine the implications of relevant uncertainties. We agree that it would be unsatisfactory if the safety case were to be based on an unsupported assumption concerning a key parameter. Our focus is on a better understanding of the inventory that could give rise to C-14-labelled gas and the adoption of relatively simple assumptions concerning the time period for the evolution of gas. We wish to avoid undue reliance on uncertain microbiological models.</p>	<p>NRF_011.1 and NRF_011.2 – Issues closed</p> <p>Only C-14 output from GRM is used directly in the 2011 ESC gas pathway assessment and LLW Repository Ltd used the inventory data to determine the release of C-14 from waste materials. C-14 is mainly associated with the mild steel materials. Thus the significance of the initial microbe concentration and the reliance on microbiological models in determining the release of C-14 is significantly reduced.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		analyses.		
NRF_012	Near-Field Interactions	<p>NRF_012.1</p> <p>Provide detailed information regarding the chemical and physical composition, and properties of the superplasticiser used in the Drigg grout backfill, document an assessment of the potential effects of the superplasticiser on radionuclide migration and overall disposal system performance, and demonstrate that the formulation of the Drigg grout backfill and the nature of the Vault wasteform represent BPM for ensuring that doses and risks are ALARA, economic and social factors being taken into account.</p> <p>NRF_012.2</p> <p>Provide detailed information on the materials of the 'over vault drainage blanket', the 'inter-ISO (International Organisation for Standardisation) container drainage' and the 'vertical drain', document an assessment of the compatibility of these materials with the waste and the host rock, and demonstrate that the design of these engineering features</p>	<p>NRF_012.1 – Work completed in relation to superplasticiser and work on the wasteform in hand or planned for the 2011 ESC</p> <p>Subsequent to the 2002 PCSC, a review of the potential impact of superplasticiser has been undertaken and concluded that impacts are likely to be small (Trivedi et al. 2008).</p> <p>Further consideration of the wasteform is planned as part of preparatory work for the 2011 ESC.</p> <p>NRF_012.2 – Rejected / not relevant</p> <p>Optimisation studies will be completed before the 2011 ESC in relation to the design of the facility. We would not propose to undertake a specific optimisation study for each individual sub-component of the facility unless it were clear that there is a major link between that sub-component and overall performance.</p> <p>NRF_012.3 – Rejected /</p>	<p>NRF_012.1 – Issue closed - subsumed into IRF ESC-TQ-INF-026</p> <p>LLW Repository Ltd addressed the initial part of NRF_012.1 through the work reported in Trivedi et al. (2008). This report details information on the superplasticisers used in the grout backfill. It also details international research experience on radionuclide leaching and complexation to assess the potential effect of superplasticisers on radionuclide transfer.</p> <p>LLW Repository Ltd also assessed the effect of zero adsorption and complexation through a sensitivity study. In this extreme case the risk guidance level is only just exceeded. We accept that this is unlikely to occur. However, we noted that LLW Repository Ltd assessed the effect of solubility and adsorption separately and that no assessment was made of the combined effect of high solubility and no adsorption. We raised this issue in IRF ESC-TQ-INF-026 (see NRF_010.2). In response, LLW Repository assessed a combined variant case that addressed our query.</p> <p>We note that, after the submission of the 2011 ESC, LLW Repository Ltd had to change the superplasticiser used in its grout formulation. The company successfully demonstrated the formulation change did not have any safety performance implications.</p> <p>NRF_012.2 – Issue carried through to ESC-FI-023</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>and the nature of the chosen materials represent BPM for ensuring that doses and risks are ALARA, economic and social factors being taken into account.</p> <p>NRF_012.3</p> <p>Document clearly the potential significance to site risks of trench-to-vault uranium transfers. Provide further information that allows clear understanding of the amounts and spatial distribution of possible uranium transfers between the trenches and vaults as a result of cross-flow (for example, two-dimensional plan views of the disposal facility, representing the spatial distribution and evolution of chemical conditions over time). Document more fully the uncertainties associated with the 2002 PCSC modelling of trench-vault interactions. If trench-vault uranium transfers are significant to site risks, take account of the potential effects of spatial heterogeneity in near-field water flows and of physico chemical processes (for example, grout hydration, passivation of fracture</p>	<p>disproportionate</p> <p>We will discuss such interactions and any related bias. However, we consider that a detailed evaluation and modelling of such effects is disproportionate. We consider that there are other near-field FEPs that are more important to prioritise for further study. Our proposed approach is not to represent every near-field FEP in an assessment model, but to conduct a systematic evaluation, supported by appropriate arguments and models.</p>	<p>LLW Repository Ltd has altered the designs of the future vaults and the post-closure engineering since the 2002 PCSC. Certain features that were proposed in the 2002 PCSC are no longer relevant to the 2011 ESC, for example the vertical drains. However, other features are still relevant to the 2011 ESC, for example the inter-container drainage and the overvault drainage blanket. Although further information on these features has been provided, sufficient to demonstrate consistency with the GRA, we consider that this issue has not been fully addressed to the extent required before further construction takes place. For example, the granular material within the inter-container drainage has not been assessed for compatibility with the waste or host rock and there is not a significant amount of information that relates to the material that will be used. We also consider that features like the inter-container drainage have not yet been fully demonstrated to represent BAT. Similarly, we consider that LLW Repository Ltd has not fully demonstrated that potential issues such as blockages in the drainage between the containers are consistent with providing a case. We ask LLW Repository Ltd to assess the long-term performance of the leachate management system in FI ESC-FI-023. We expect the provision of appropriate details covering the management of leachate across the vaults to be developed and assessed as part of the design justification process in advance of further</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		surfaces) that may influence the retention of uranium in the vaults.		<p>construction.</p> <p>NRF_012.3 – Issue closed</p> <p>This IAF queried understanding of the effect of uranium transfer from the trenches to the vaults. This issue is of less concern in the 2011 ESC than in the 2002 PCSC because it is believed that disruption of the LLWR will occur prior to significant mobilisation of the uranium. The extent of mobilisation of uranium is dependent on the oxidation states of the uranium and it is ascertained from GRM studies that significant mobilisation of uranium will not occur within the expected timescale prior to the onset of coastal erosion.</p>
NRF_013	Near-Field Sorption	<p>NRF_013.1</p> <p>Provide further information on the treatment of sorption in the near-field in the 2002 PCRSA, including a clear statement of the ranges of chemical conditions for which the best estimate Kd values are considered valid.</p> <p>NRF_013.2</p> <p>Undertake a broader and technically-justified set of sensitivity and uncertainty analyses.</p> <p>NRF_013.3</p> <p>Revise the approach to</p>	<p>NRF_013.1 – Accepted / planned for the 2011 ESC</p> <p>We envisage a simple treatment involving linear equilibrium distribution coefficients. We will discuss the applicability of these distribution coefficients to the chemical conditions of interest.</p> <p>NRF_013.2 – Accepted / planned for the 2011 ESC</p> <p>As part of our analysis of uncertainty, we will undertake sensitivity studies.</p> <p>NRF_013.3 – Rejected / disproportionate</p>	<p>NRF_013.1 – Issue closed - subsumed into IRF ESC-TQ-INF-026</p> <p>In the elicitation of uncertainties work, Jackson et al. (2011) provide evidence for the chosen Kds adopted for uranium and technetium under trench and vault like conditions. A review of near field sorption data for all radionuclides is provided in Appendix D of Kelly et al. (2011). LLW Repository Ltd produced a reasoned argument as to why the distribution of Kds has been chosen. We note that, in particular, the Kds for uranium do not cover as wide a range as those cited for similar studies carried out by NIREX; this issue was raised in IRF ESC-TQ-INF-026 and subsequently addressed to our satisfaction (see NRF_014.1).</p> <p>NRF_013.2 – Issue closed - subsumed into</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>modelling near-field sorption so that the evolution of chemical conditions is taken into account.</p> <p>NRF_013.4</p> <p>Consider investigating further the effects on radionuclide sorption of additional near-field solid phases (for example, iron corrosion products).</p> <p>NRF_013.5</p> <p>Commit to conducting work under the forward programme aimed at developing a defensible approach to the treatment of sorption in the near-field.</p>	<p>We will consider the relevant FEPs and discuss and evaluate any potential effects. We consider, however, that it would be disproportionate to develop an assessment model with such a complex representation of chemistry.</p> <p>NRF_013.4 – Rejected / disproportionate</p> <p>There will be beneficial effects from sorption to such phases, but the safety case would be cautious in ignoring such effects.</p> <p>NRF_013.5 – Rejected / disproportionate</p> <p>We consider that the treatment of sorption in the 2002 PCSC is appropriate for assessment purposes, although arguments could be improved in relation to parameter choices. We note that the equilibrium sorption model produces very conservative estimates of contaminant concentrations in trench leachate compared to observation.</p>	<p>IRF ESC-TQ-INF-026</p> <p>LLW Repository Ltd has assessed the effects of zero adsorption as a variant case in the groundwater pathway assessment. Uranium (through its daughters at very long timescales) and technetium are two of the key radionuclides that present the highest risk via this pathway.</p> <p>As discussed under NRF_10.1, we queried why the variant cases of solubility and adsorption were kept separate and why LLW Repository Ltd did not assess the effect of combined solubility and adsorption variant cases in IRF ESC-TQ-INF-026. In response, LLW Repository Ltd assessed a combined variant case that addressed this specific issue.</p> <p>NRF_013.3 – Issue closed</p> <p>Although LLW Repository Ltd considers this issue to be disproportionate, it assessed the effect of different conditions within the vaults / trenches, including the effect on such species as uranium using GRM (Small et al. 2011a). LLW Repository Ltd also reviewed sorption properties of key radionuclides and the effect on adsorption with time (Jackson et al. 2011). We note that to carry out the modelling requested in NRF_013.3 would be complex and consider that what has been presented within the 2011 ESC is proportionate.</p> <p>NRF_013.4 – Issue closed</p> <p>The effect of changes to near field conditions and the potential consequences for adsorption</p>

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				<p>properties is assessed in Jackson et al. (2011).</p> <p>NRF_013.5 – Issue closed</p> <p>We agree that a demonstrably conservative approach is 'defensible' in assessments for compliance.</p>
NRF_014	Near-field mineralogy	<p>NRF_014.1 Document the justification for the inclusion/exclusion of solid mineral and radionuclide phases in the DRINK database by reference to observations and/or the results of thermodynamic speciation calculations for relevant chemical/geochemical systems.</p> <p>NRF_014.2 Document further evidence for the adequacy of the cement dissolution model adopted in DRINK.</p> <p>NRF_014.3 Provide further information to demonstrate that the automatic reaction path model used in the GRM code for resolving mineral oversaturations and undersaturations adequately addresses uncertainties such as temporary disequilibrium of multiple-mineral systems,</p>	<p>NRF_014 all parts – Partly reduced relevance but the comments will be considered ongoing work</p> <p>These are comments related to the use of DRINK. DRINK will not have such a central role in future assessments so the recommendations are less pressing than would have been the case.</p> <p>We will consider the comments as part of a review and update of DRINK, which is to commence shortly.</p>	<p>NRF_014.1 – Issue closed - subsumed into IRF ESC-TQ-INF-026</p> <p>The majority of the source term used in the 2011 ESC assessment is no longer provided by DRINK/GRM (to which this issue relates). Jackson et al. (2011) provide solubility values for both uranium and technetium and give the ranges for uranium and technetium that were used in the assessment. We questioned whether the ranges applied are suitable in IRF ESC-TQ-INF-026 (see NRF_013.1). The response supplied by LLW Repository Ltd adequately addressed our concerns.</p> <p>NRF 014.2 – Issue carried through to ESC-FI-014</p> <p>DRINK/GRM has a less central role in the assessment process in the 2011 ESC compared with the 2002 PCSC. C-14 is the only radionuclide for which the output from GRM is taken forward to the assessment.</p> <p>Within the GRM study, LLW Repository Ltd assessed how different percentages of grout will affect the pH of the near field in terms of the distribution of C-14 to the gas, solid and groundwater phases and the resultant</p>

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		dominant undersaturation of an absent phase, and the possibility of inappropriate phases in a system with a range of chemical environments.		<p>radiological impact (Small et al. 2011a). LLW Repository Ltd also assessed an extreme case where no grout is present within the near field and showed that the metals present within the near field will offer the buffering capacity required after 200 years.</p> <p>We accept that this IAF has been addressed, but note that, in the future, the quantities of cement and metal disposed of to the LLWR could change as a result of the opening of new waste disposal routes and that this could affect the near field. We expect LLW Repository Ltd to update the GRM (or alternative near field model) modelling and assessments as and when such changes occur to ensure that the ESC remains appropriate. This issue is being taken forward via ESC-FI-014.</p> <p>NRF_014.3 – Issue closed - subsumed into IRF ESC-RI-ASO-005 and ESC-TQ-INF-026</p> <p>The reaction path model is only relevant to mineral phases affecting C-14 behaviour. Uncertainties in this model are covered by the C-14 sensitivity study and also in the response to IRF ESC-RI-ASO-005 on C-14. We queried the approach to assessing phase control solubility within the elicitation exercise in IRF ESC-TQ-INF-026. LLW Repository Ltd addressed this query to our satisfaction.</p>
NRF_015	Radionuclide screening	NRF_015.1 Demonstrate that the PCRSA includes all radionuclides of	NRF_015.1 – Accepted / In hand or planned for the 2011 ESC	<p>NRF_015.1 Issue closed</p> <p>The issues raised in this IAF are addressed in LLW Repository Ltd's radiological handbook</p>

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		<p>potential significance and improve the screening presented in the 2002 PCRSA by:</p> <ul style="list-style-type: none"> a) documenting the justification for the exclusion of the seafood exposure pathway from the calculations used to screen radionuclides for the groundwater pathway, b) documenting the justification for the exclusion of the external irradiation pathway from the calculations used to screen radionuclides for human intrusion, c) documenting which radionuclides were modelled for the natural termination events (glaciation and coastal erosion), d) documenting the justification for the exclusion of radionuclides from the PCRSA calculations for the groundwater pathway on the basis of a small calculated dose compared to tritium (H-3), or documenting results from further assessment calculations for radionuclides excluded from the 2002 PCRSA. 	<p>As a preparation for the 2011 ESC, we will review the radionuclide screening calculations. However, screening calculations must necessarily make approximations and simplifications or they would not be screening calculations. The following specific observations are noted.</p> <ul style="list-style-type: none"> a) The impacts via the seafood exposure pathway are very low and key radionuclides expected to be the largest contributors are screened in. b) It would seem reasonable to include rather than exclude external irradiation, since this exposure pathway is a dominant contributor in some cases. c) We agree that this is necessary. d) The screening calculations will need to be reconsidered in the light of the importance of the water abstraction well. 	(Thorne et al. 2011).
NRF_016	Near-field microbiologica	NRF_016.1 Provide more detailed	NRF_016.1 – Mainly rejected / disproportionate	NRF_016.1 – Issue closed with recommendation

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
	I model description, assumptions and justification	<p>information on the chemical composition of materials in the Drigg disposal facility to demonstrate that all potentially significant sources of nutrients and energy for microbial activity have been taken into account.</p> <p>NRF_016.2 – no Recommendation</p> <p>NRF_016.3</p> <p>Provide information that records clearly how and why each individual microbiological near-field FEP has been considered in the PCRSA.</p> <p>NRF_016.4</p> <p>Document the logical links between the near-field Conceptual Model Uncertainty (CMU) forms and the geosphere-near-field interactions CMU forms.</p>	<p>DRINK will be reviewed. However, microbiological models of the sort under discussion are inherently uncertain. We therefore intend that the assessment should be based as far as possible on simpler arguments for example an analysis of the form of C-14 within the inventory, sensible assumptions about the timescale over which it might be released and monitoring data. It is noted that a small fraction of the inventory of C-14 is associated with cellulosics (currently the subject of investigation) so that such microbiological effects are less important.</p> <p>NRF_016.3 – No longer relevant / superseded</p> <p>The simplified approach envisaged would not require such a detailed analysis of microbiological FEPs. Nevertheless, a review of FEPs and their documentation are important. This is planned.</p> <p>NRF_016.4 – No longer relevant / superseded</p> <p>This recommendation is</p>	<p>The materials associated with C-14 in the LLWR inventory are predominantly metallic. C-14 is the only species where the data obtained from GRM is a direct input to the assessment process. The C-14 release rate from materials will be less dependent on microbiological processes than believed at the time of the 2002 PCSC, when C-14 was primarily thought to be primarily associated with cellulose materials. Thus other carbon energy sources, such as superplasticisers, for microbial species will have less effect on the release of activity from the near field. With regard to the gaseous pathway, the predominant material present is cellulosic and the fraction of gas that the degradation of other materials would make to the overall gas production is expected to be low. However, we note that it is not clear whether graphite will act as an energy source under anaerobic conditions and a watching brief should be maintained on this topic (Recommendation INF26).</p> <p>NRF_016.2 – Issue closed</p> <p>Although no recommendation is provided under NRF_016.2, the Near Field Review Group stated that 'information is needed to confirm that superplasticiser used in grout is not an additional source of non-synthetic organic carbon which could be utilised by microbes' (Galson Sciences Ltd and Environment Agency 2004).</p> <p>LLW Repository Ltd commissioned a review of the properties of Sikament-10 (Trivedi et al. 2008), which concluded that the Sikament-10 will</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
			superseded as we do not propose such a complex approach in the 2011 ESC.	<p>remain bound to the cement fractions and thus will not be freely available to enhance the release of radionuclides from the near field area. According to Trivedi et al. (2008), degradation of Sikament-10 will provide an energy source for microbes, resulting in the production of small chain organics and CO₂, appearing to suggest that this material can act as an energy source and will add to the production of gas from the facility and potentially increase the probability of this gas acting as a carrier gas for C-14.</p> <p>Since 2008, LLW Repository Ltd has carried out further investigations into the behaviour and characteristics of a replacement to Sikament-10 in the grouted wasteform. These investigations confirmed that revised formulation superplastisers are effectively bound to the grout matrix (Randall et al. 2011). We accept that superplasticisers such as Sikament-10 and its replacement, Sikament-700, could result in very small quantities of gas generation. However, we consider that, because of the low concentration of superplasticiser in the grout and availability for microbial degradation, the potential gas volume generated as a result of superplasticisers is insignificant compared with the overall predicted production rates of C-14 carrier gas used in the 2011 ESC. We therefore consider that no further investigation into the role of superplasticisers is warranted.</p> <p>NRF_016.3 - Issue carried through to FI ESC-FI-014</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
				<p>Within the FEP and uncertainty tracking system, microbial FEPs have been reviewed for the vault environment, focusing on how future waste forms might affect the behaviour of microbes and on improving the understanding of microbial reactions within a vault environment (LLW Repository Ltd 2013).</p> <p>In the 2011 ESC, GRM has been used to assess the effects of such microbial FEPs. We note that changes to the treatment of future waste streams may influence these effects. We recommend that LLW Repository Ltd continues to monitor the effects of future treatments and future wasteforms on the near field environment (ESC-FI-014).</p> <p>NRF_016.4 – Issue no longer relevant</p> <p>CMU forms are not used in the 2011 ESC, but we would expect that considerations of conceptual model uncertainty should take into account the interfaces between models.</p>
NRF_017	Near-Field Microbiological Parameters and Significance	<p>NRF_017.1 Provide clear documentation of the links between FEPs and parameter values to show which FEPs are captured within each parameter.</p> <p>NRF_017.2 Document the rationale for sensitivity analyses to address uncertainty in microbiological</p>	<p>NRF_017.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>If any FEPs are treated by adjusting parameter values, then clear documentation of this will be required. This will be achieved by appropriate records in data entry forms.</p>	<p>NRF_017.1 – Issue closed</p> <p>Uncertainty in FEPs and associated parameter values is discussed in the FEP and uncertainty tracking system (LLW Repository Ltd 2013). This IAF relates primarily to uncertainty associated with the degradation of waste within the facility, in particular relating to the vault wasteform. LLW Repository Ltd assessed a number of deterministic variant cases to understand the distribution of C-14 between the gas and groundwater pathways. This investigation was</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		parameter values and conceptual models, and demonstrate that all relevant microbiological uncertainties have been adequately assessed.	relevant The simplified approach noted under NRF_016 would not require such a detailed analysis. We are proposing an assessment based primarily on simple assumptions rather than complex microbiological models, so the importance of the recommendations is reduced in LLW Repository Ltd's view.	sufficient to allow closure of this IAF. NRF_017.2 – Issue no longer relevant The near field modelling makes direct use only of C-14 data from GRM. LLW Repository Ltd assessed the sensitivity to changes in various parameters of C-14 radiological impacts via the gas and groundwater pathways and solid mass generation (Small et al. 2011a). We consider that the need for sensitivity analysis to address microbiological uncertainty is of less relevance to the 2011 ESC than it was to the 2002 PCSC; uncertainties relating to the release of C-14 from the wasteform are more significant.
NRF_018	Near-Field Performance and Microbiological Uncertainties	NRF_018.1 Document an assessment of the effects of spatial heterogeneity of waste on biogeochemical evolution and radionuclide solubilities within the repository. NRF_018.2 Document a clear evaluation of the significance of microbiological and other assumptions in the aqueous source-term model to dose and risk estimates in the PCRSA calculations.	NRF_018.1 – Accepted / In hand or planned for the 2011 ESC We have undertaken work and will undertake future work to investigate the effects of spatial variation in the near field. We will focus on those effects that we judge to be the most significant and document the arguments. NRF_018.2 – No longer relevant / disproportionate Our overall approach will be to base the assessment calculations on relatively simple models. We consider that an in-depth analysis of	NRF_018.1 – Issue closed LLW Repository Ltd carried out an assessment of the impact of waste heterogeneity on the evolution of the near field. The company used GRM to compare the radiological impacts for the case where waste is distributed evenly through the trenches/vaults with that where specific wastes have been placed within each disposal cell (Small et al. 2011a). This demonstrated that there is little effect on the outputs from the GRM model. However, we note that at present this work has not been fully completed and that LLW Repository Ltd still has to demonstrate that, once the vault is full, the effects of heterogeneity are still not significant in terms of the assessment. In addition, we note that, until additional vaults are full, the effects between vaults cannot be assessed. We support LLW Repository Ltd's progress in using the GRM to assess the effects

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
			every related FEP would be disproportionate.	<p>of heterogeneity and recommend that it continues to model this for the vaults. We are confident that sufficient information from future waste disposals can be collected for use in future vault heterogeneity assessments.</p> <p>NRF_018.2 Issue no longer relevant</p> <p>As discussed under NRF_017.2, we consider that microbiological uncertainty is of less relevance to the 2011 ESC than it was to the 2002 PCSC.</p>
NRF_019	Isotopic Fractionation	<p>NRF_019.1</p> <p>Present an analysis of the potential effects of isotopic fractionation among hydrogen isotopes.</p>	<p>NRF_019.1 – Rejected / disproportionate</p> <p>Isotopic fractionations are very small compared to the other effects under consideration and would provide only a very small contribution to uncertainty. We do not see a need for further analysis, although the topic can be mentioned in the ESC.</p>	<p>NRF_019.1 – Issue closed</p> <p>We agree that detailed analysis of the potential effects of isotopic fractionation among hydrogen isotopes would be disproportionate for the 2011 ESC. We note that contribution to overall radiological impact from the dose contributions of organically bound tritium and tritiated water would not substantively affect any conclusions.</p>

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10. Appendix 5. GEO IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comment on LLW Repository Ltd's position
GEO_001	Planning and adequacy of site characterisation programme – geology and hydrogeology	<p>GEO_001.1 Document and justify more precisely how data and conclusions from BNFL investigations have been selected for inclusion in the Interpretation Reports (BNFL, 2002a, 2002b). In particular, explain why data and conclusions offered in lower-level reports concerning palaeo-depressions within the drift have been omitted from the Level II Interpretation Reports.</p> <p>GEO_001.2 Demonstrate the reliability and representative nature of the hydrogeological information obtained from the (unweathered) Ormskirk Sandstone in and around the Drigg site, and specify how new information will be collected.</p> <p>GEO_001.3 Provide explicit information concerning the effects of</p>	<p>GEO_001.1 to 1.3 – Accepted / Satisfied by work completed since 2002</p> <p>Work on the geological and hydrogeological conceptualisations has progressed considerably since 2002. Site investigation work as part of the Modular Vaults project along combined with the Phase 1 and 2 geological conceptualisations (Hunter et al. 2007; Smith 2007) provided an updated interpretation of the geological setting and the development of a 3D geological model of both the Quaternary drift deposits and the Ormskirk sandstone. This work will be continued with the investigations of the large exposures of drift deposits seen as part of the Vault 9 excavation work. Additional boreholes are also planned to provide further data on both the shallow and deep deposits between the site and the coast.</p> <p>A 3D hydrogeological model</p>	<p>GEO_001.1 – Issue closed The 2011 ESC utilises a different hydrogeological model with a completely different approach to the management of data.</p> <p>GEO_001.2 – Issue closed The site investigations carried out on the Ormskirk Sandstone have improved the quality of geological data. All information was collected using appropriate site investigation, logging and characterisation procedures.</p> <p>GEO_001.3 – Issue closed Post-2002 site investigations, including a geophysical survey (Halcrow 2010) and a programme of borehole based site investigation, have provided an improved understanding of the nature and significance of glacio-tectonic features in the vicinity of the LLWR.</p> <p>During our review of the 2011 ESC we noted a number of glacio-tectonic features present in geology exposed during the construction of Vault 9. These features were seen to be associated with small-scale contemporaneous faulting of glacial drift materials. The presence of small scale glacio-tectonic features within the Quaternary sequence is accounted for in attributing uncertainty to the spatial extent of high permeability (sand/gravel/cobble) lithologies. A post-2011 ESC assessment of the</p>

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		<p>glacio-tectonic features on groundwater flow at the Drigg site.</p> <p>GEO_001.4</p> <p>Augment the good quality, but sparse, hydraulic data from both the shallow and the deeper drift formations in the region between the site and the coast.</p>	<p>(Arthur et al. 2008) has been developed for the site which has been used to investigate and subsequently update the hydrogeological conceptual model (Henderson 2008a). Further work to refine the hydrogeological model is planned to provide the information on potential groundwater pathways for the 2011 safety assessment.</p> <p>On the specific recommendations:</p> <p>GEO_001.1 is concerned with the documentation structure of the 2002 PCSC and is superseded as new documentation will be prepared for the 2011 ESC.</p> <p>GEO_001.2 has been addressed as part of the site investigation work carried out since 2002 and by the planned boreholes between the site and the coast</p> <p>The effect of glacio-tectonic features (GEO_001.3) will have some impact on the distribution of lithologies at the site. A programme of work will consider the implications of our</p>	<p>effect of faults on the hydrogeology at the LLWR, included an assessment of glacio-tectonic faulting, is provided in Woppard and Jackson (2012).</p> <p>We are confident that the information presented since the 2002 PCSC on the extent and nature of glacio-tectonic features will not significantly change the predicted groundwater flows assessed in the 2011 ESC. We conclude that the presence of glacio-tectonic features increases the complexity of the Quaternary geology but does not require specific conceptualisation within the groundwater models.</p> <p>LLW Repository Ltd should continue to utilise all visual and geological log information in order to improve understanding of the Quaternary geological sequence, including the nature and extent of high permeability sequences that will form part of the under liner drainage capacity.</p> <p>GEO_001.4 – Issue closed with recommendation</p> <p>The area of land between the repository and the current coastline is the main groundwater pathway and the key area of interest in determining the rate of coastal recession. The area currently does not have an extensive level of intrusive characterisation and investigation because of its status as a Special Area of Conservation and Site of Special Scientific Interest.</p>

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			<p>broad understanding of spatial variation.</p> <p>GEO_001.4 – Accepted / Satisfied by work planned in support of the 2011 ESC</p> <p>Will be addressed by the planned boreholes between the site and the coast.</p>	<p>Since the 2002 PCSC, LLW Repository Ltd has carried out a substantial site investigation and geophysics programme adjacent to, and within, the area between the repository and the coast. This information has significantly increased the understanding of the shallow drift sequence. In particular the geophysical programme carried out in 2010 allowed visualisation of the relationship between the Quaternary drift and underlying geology (Halcrow 2010). LLW Repository Ltd used this information to inform the hydrogeological model and coastal recession model used in the 2011 ESC (LLW Repository Ltd 2011d).</p> <p>Despite the significant improvements in the characterisation of this area of land, the level of uncertainty in the understanding of the Quaternary geology remains high. We recognise the access limitations that make intrusive site investigation difficult. We recommend that LLW Repository Ltd maximises its use of the geological information it has and follows all practical and reasonable opportunities to gather geological information in the area between the LLWR and the coast where possible (Recommendation SUE3).</p>
GEO_002	Planning and adequacy of site characterisation programme – hydrogeological	<p>GEO_002.1</p> <p>Develop a 3-D geological model to present / interpret the site geology.</p> <p>GEO_002.2</p>	<p>GEO_002.1 – Accepted / Work completed since 2002</p> <p>A 3D geological model of the site has been developed (Smith 2007), which addresses GEO_002.1. The model has</p>	<p>GEO_002.1 – Issue closed</p> <p>Issue closed with respect to the development of a 3D geological model (Smith 2010). Comments on the transparency of documentation and flow through of information from the geological conceptualisation to the 3D geological model</p>

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	modelling	<p>Determine the appropriateness of the 'layered cake' hydrogeological model and explore its associated uncertainty by using 3-D stochastic facies models to represent alternative conceptual models of the hydrogeology of the site.</p> <p>GEO_002.3</p> <p>Justify why, in BNFL's suggestions for the forward programme, the determination of permeability values is based on measurement of samples while, in the PCRSA, mostly the in situ measurements were considered valid.</p>	<p>been updated with new data as it has become available and has also been used to predict the geology of the proposed boreholes between the site and the coast.</p> <p>GEO_002.2 /2.3 – Accepted / In hand or planned for the 2011 ESC</p> <p>Work has been carried out recently on alternative geological conceptual models (Serco 2008a) and to determine whether a stochastic representation (Serco 2008b) of the system can be developed. This work is specifically considering the connectivity of individual layers and the validity or otherwise of the 'layer-cake' model.</p> <p>We are considering all sources of permeability data, but note that the two sorts of measurement identified in GEO_002.3 address different lengthscales. We will justify our approach to parameterisation in presenting the hydrogeological model for the 2011 ESC.</p>	<p>and to the hydrogeological model are covered in GEO_005.1.</p> <p>GEO_002.2 – Issue closed</p> <p>The 2011 hydrogeological model was based on the early 2010 3D geological model, which was updated later in 2011, and calibrated using site data (Hartley et al. 2011a). The effect of alternative conceptualisations was investigated, including the updated September 2010 3D geological model, the groundwater mound and spatial variability in the lithofacies units. A probabilistic version of the 2010 compartment flow model was also run, which considers variability in a limited number of parameters.</p> <p>GEO_002.3 – Issue closed with recommendation</p> <p>Calibration of the numerical hydrogeological models was dominated by modification of hydraulic conductivities, within specified ranges, to improve the fit of models with observed data. With reference to the data presented by Hartley et al. (2011a), we note that the correlation between calibrated model data and site data appears reasonable for lithofacies units C and D and the upper sandstone. However, the model values for B3 (in particular for sand and gravel) seem high, whilst the model vertical conductivity for B2 seems very low compared with site data (noting that borehole data represent local properties whilst the model data represents properties over longer distances).</p>

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				Although we have concluded that the hydrogeological assessment produced to inform the 2011 ESC was comprehensive and robust utilising appropriate site derived information, we have asked LLW Repository Ltd to clearly substantiate its choice of parameters and data ranges used in the calibration of future hydrogeological models (Recommendation SUE18).
GEO_003	Planning and adequacy of site characterisation programme – geochemistry	<p>GEO_003.1 Continue to monitor for tritium in groundwater, and use the data to improve understanding of flow paths.</p> <p>GEO_003.2 Regularly monitor between the site and the coast to evaluate discharges from the Upper Groundwater and Regional Groundwater to the coastal area and to the north-west of the site.</p> <p>GEO_003.3 Establish the reason for similar tritium concentrations in the under- and over-slab components of the Vault 8 drain (for example, discharge of contaminated groundwater into the over-slab drain, or mixing of over-slab and under-</p>	<p>GEO_003.1 – Accepted / In hand or planned for the 2011 ESC Monitoring of tritium concentrations in groundwater has continued and is an input to our understanding of flow paths.</p> <p>GEO_003.2 – Accepted / In hand or planned for the 2011 ESC Monitoring is undertaken to identify potential discharges of radioactive contamination to surface receptors.</p> <p>GEO_003.3 – Accepted / work complete The tritium contamination in the Vault 8 drain is considered to derive from the trenches and mixing at the measurement point is considered to be the</p>	<p>GEO_003.1 - Issue carried through to FI ESC-FI-002</p> <p>In our review of the Schedule 9 Requirement 2 (of the current Environmental Permit) submission, we recommended that LLW Repository Ltd committed further effort to developing a clear understanding of the mechanisms controlling the release and migration of tritium within the groundwater (Environment Agency 2009).</p> <p>The 2011 ESC includes an assessment into the distribution and behaviour of the tritium plume, including use of monitoring data to estimate how much tritium has been lost from the trenches (Henderson 2011). The tritium plume has been used as a marker to assist in the validation of the groundwater models.</p> <p>We are satisfied that monitoring of tritium in groundwater is continuing as part of the routine LLWR environmental monitoring programme. The output from this monitoring should be used to confirm that the predicted decline in tritium concentrations is occurring, to improve</p>

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		<p>slab waters at the measurement point).</p> <p>GEO_003.4</p> <p>Consider an investigation of man-made contaminant concentrations along flow paths to help a more detailed analysis of preferential flow paths and flow rates.</p> <p>GEO_003.5</p> <p>Consider undertaking a spatial analysis of hydrochemistry, considering both depth and location with regard to flow-defining features, to help a more detailed analysis of flow paths and rates.</p> <p>GEO_003.6</p> <p>Undertake reaction path modelling between water samples along flow paths to build confidence in the geochemical interpretation and the PCRSA assumptions.</p> <p>GEO_003.7</p> <p>Present the basis for selecting sample K114 as the representative groundwater composition, both for the near-field modelling and the</p>	<p>reason for the similar concentrations in the under and overslab components.</p> <p>GEO_003.4</p> <p>The monitoring of non-radiological contaminants has been incorporated into the site environmental monitoring programme. This will provide an opportunity to assess whether such contaminant concentrations can be used to assess flow paths.</p> <p>GEO_003.5 – Accepted / work complete</p> <p>Spatial analysis of hydrochemistry has been incorporated into the development of the hydrogeological conceptual model. In particular the analysis of tritium concentration have been used to assess flow paths and rates.</p> <p>GEO_003.6 – Rejected / disproportionate</p> <p>We consider that the likely benefits of a spatial analysis of the hydrochemistry and reaction path modelling do not justify the cost and have</p>	<p>understanding of flow paths and, where possible, build confidence in the output of groundwater models (ESC-FI-002). LLW Repository Ltd should also consider how tritium data can help understand the impact of the placement of surcharging material and the final trench cap on tritium remaining within the trenches.</p> <p>GEO_003.2 - Issue carried through to ESC-FI-005</p> <p>Since the 2002 PCSC, LLW Repository Ltd has installed a number of additional downstream groundwater boreholes between the repository and the coast. These boreholes are capable of providing robust and comprehensive groundwater monitoring information from both the upper and regional groundwater. However, we still believe that there is scope for improvement of site investigation and monitoring capability for the land between the LLWR and the coast, although we do note and accept the access restrictions and sensitivity of the habitat within the special area of conservation.</p> <p>Only a very small number of groundwater and surface water locations are monitored to determine the potential for discharge of contamination to surface receptors between the LLWR and the coast. The use of monitoring to reduce key uncertainties in the ESC is further addressed in IRF ESC-RO-SUE-007 and ESC-FI-005.</p> <p>Geo_003.3 - Issue closed</p>

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		<p>sorption modelling.</p> <p>GEO_003.8</p> <p>Consider the potential for sealing of porosity and generation of colloids in further work on the processes occurring at the near-field / far-field interface.</p> <p>GEO_003.9</p> <p>Present a more detailed forward plan.</p>	<p>prioritised other areas of work.</p> <p>GEO_003.7 – Accepted / In hand or planned for the 2011 ESC</p> <p>Review of data quality will be carried out as part of the groundwater monitoring.</p> <p>GEO_003.8 – Accepted / In hand or planned for the 2011 ESC</p> <p>Colloid generation at the near field / far field interface would not increase the source term, which we consider to be the potential effect of colloids that would be of most concern. Such colloids if they were transported could decrease radionuclide transport times in the geosphere, but this would have little impact as environmental receptors (such as the well) are already very close to the source of contamination. Sealing of the porosity would have a low impact since relevant bentonite and concrete barriers are already associated with a low permeability. We will discuss and present arguments in relation to a range of colloid</p>	<p>We agree with LLW Repository Ltd's interpretation of the source of tritium contamination.</p> <p>GEO_003.4 - Issue closed</p> <p>Monitoring data indicate that there appears to be no significant non-radiological contamination of the LLWR ground and surface waters. To date, there has been no opportunity to use these data to assess flowpaths. We do not consider such an exercise would deliver any improvements over the existing radiological groundwater monitoring programme.</p> <p>GEO_003.5 - Issue closed</p> <p>LLW Repository Ltd has used hydrochemical data in the 2011 ESC to support the development of the groundwater model, for example with respect to use of tritium data in a qualitative manner to assess flow paths and rates (Jackson 2011), and the role of salinity at depth and from the coast on the groundwater flow patterns (Bond 2007).</p> <p>GEO_003.6 - Issue closed</p> <p>Agreed.</p> <p>GEO_003.7 - Issue not relevant</p> <p>This issue is of specific relevance to the 2002 PCSC only. We are satisfied with LLW Repository Ltd's basis for groundwater composition presented within the 2011 ESC and used for near field and sorption modelling.</p> <p>GEO_003.8 - Issue carried through to ESC-FI-</p>

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			<p>FEPs (including these) in the 2011 ESC.</p> <p>GEO_003.9 – Accepted / work complete</p> <p>We have developed a forward plan as the basis of the LTP and have set out approach in the Safety Case Approach Document.</p>	<p>015</p> <p>The effect of colloids within the near field is discussed in the Near field Level 2 report with respect to research that supported the 2002 PCSC. For the near field we recommend that LLW Repository Ltd maintains a watching brief on developments within national and international research programmes on colloidal transport of pollutants and to apply the knowledge obtained to the effects of colloids at the LLWR (Environment Agency 2015a). We also recommend that LLW Repository Ltd evaluates undertaking a proportional monitoring programme to ensure that the 2011 ESC assumptions on colloids remain appropriate.</p> <p>The effect of colloids on geosphere travel times is not discussed in the 2011 ESC. However, in a review of the monitoring programme, LLW Repository Ltd considered a one-off study to provide improved understanding of colloids and contaminant transport (Peachey and Shevelan 2012). We support the conclusions of the review that were to propose periodic measurements to determine if the activity associated with particulates is linked to colloids. We outline our recommendations for further work in this area in ESC-FI-015.</p> <p>GEO_003.9 - Issue closed with recommendation</p> <p>This issue is considered closed with respect to the 2002 PCSC. LLW Repository Ltd's current forward monitoring plan includes assessment of</p>

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				leachate, surface and groundwater quality, but no consideration of additional geochemical characterisation, for example to analyse in more detail the processes occurring at the near field / geosphere interface. We support the conclusions of the review of the post 2011 ESC monitoring programme that were to review the existing (2002) hydrogeochemical interpretation to determine whether any update is required (Peachey and Shevelan 2012) (Recommendation SUE31). We note that LLW Repository Ltd has reviewed its monitoring strategy development since the submission of the 2011 ESC.
GEO_004	Planning and adequacy of site characterisation programme - colloids / organics / retardation (sorption)	<p>GEO_004.1</p> <p>Consider undertaking colloid mobility studies using column and field experiments similar to those carried out by the British Geological Survey (see references 15 and 16 in BNFL 2003a), since these have the potential to provide definitive answers regarding the potential for colloid transport. The studies should focus on humic and fulvic (organic) acids, as these probably have greater potential than inorganic colloids to transport radionuclides.</p> <p>GEO_004.2</p>	<p>GEO_004.1 and 2 – Rejected / disproportionate</p> <p>Colloid concentrations sampled in trench leachate and far-field groundwater are low. Colloid concentrations in the vaults would also be expected to be low (owing to the presence of cements). In comparison with other uncertainties, the role of colloids is likely to be low. Further, we consider that enhancements to the source term are likely to be more significant than any impact on geosphere transport. Therefore, LLW Repository Ltd does not consider that these areas of research are a priority.</p>	<p>GEO_004.1 and 004.2 - Issues carried through to ESC-FI-015</p> <p>We accept much of LLW Repository Ltd's argument that this area of characterisation is of low priority relative to other areas. However, as discussed under GEO_003.8, we recommend that LLW Repository Ltd periodically undertakes crude measurements to determine if the activity associated with particulates is linked to colloids. This issue is taken forward in ESC-FI-015.</p> <p>As discussed in Appendix 4 (NRF) we consider LLW Repository Ltd has adequately and conservatively assessed solubility.</p>

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		Conduct further research into radionuclide-fulvic acid stability constants, dissociation kinetics, and models (including PA) incorporating these parameters.	The potential influence of colloidal processes will be addressed in the 2011 ESC and relevant arguments and data will be presented.	
GEO_005	Adequacy of information / referencing – overall PCSC document structure	GEO_005.1 Improve the structure and clarity of reporting in a future PCRSA.	GEO_005.1 – In hand or planned for the 2011 ESC The Structure of the ESC was discussed in the Safety Case Approach Document (Baker et al. 2008). There will be an improvement relative to the 2002 PCSC.	GEO_005.1 - Issue closed with recommendation Overall we agree that the structure and clarity of the 2011 ESC is an improvement over the 2002 PCSC. We are also satisfied that LLW Repository Ltd has suitable quality systems in place to manage the production of future ESC updates. However, as with many large and complex cases, we believe there remains scope for improvement and we did identify a number of areas which lacked clarity within the 2011 ESC. Some of the issues raised under GEO_005.1 remain relevant. These areas for potential improvement are identified elsewhere (for example, Environment Agency 2015b). For example, there could have been greater clarity within the 2011 ESC on the interaction between and development of, various 3D hydrogeological models in the run up to completion of the 2011 ESC. We consider that LLW Repository Ltd should continue to work to improve the structure and presentation of reporting. We expect models being used within the ESC to continue to be clearly identified and to have clear audit trails

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				(Recommendation SUE4).
GEO_006	Adequacy of information / referencing - geological and hydrogeological characterisation	<p>GEO_006.1 Ensure uniformity of stratigraphic and geological nomenclature in all relevant top-level reports.</p> <p>GEO_006.2 Provide necessary data or references to justify statements in the Geological Interpretation on source-diagnostic clast compositions of various drift deposits.</p> <p>GEO_006.3 Provide information on the sampling, analytical and presentational techniques used in constructing the ternary and summary particle size distribution pie-diagrams for all drift formations.</p> <p>GEO_006.4 Provide an account within the context of Geological Interpretation, of existing knowledge of Late Quaternary sea-level change in the Drigg region, including an assessment of the Drigg Quaternary sequence in</p>	<p>GEO_006.1 – Accepted / Satisfied by work completed since 2002 It is recognised that presentation of the geology needs to be consistent on both a site and regional scale and this will be addressed in the presentation of the geological understanding in the 2011 ESC. Actions are incorporated into geological model report.</p> <p>GEO_006.2 – Accepted / Satisfied by work completed since 2002 Clast composition has been considered as part of the geological re-interpretation (Smith 2007)</p> <p>GEO_006.3 – Accepted / to be include in the 2002 ESC Supporting information for constructing diagrams will be clearly referenced in the 2011 ESC.</p> <p>GEO_006.4 – Accepted / Satisfied by work completed since 2002 Smith (2007) presents the</p>	<p>GEO_006.1 - Issue closed Agreed, whilst noting that the nomenclature has changed between the 2007 and 2010 geological interpretations. Michie et al. (2010) provides a mapping of geological nomenclature between the different geological models.</p> <p>GEO_006.2 - Issue closed The role of clast composition in the characterisation and identification of specific glacial facies is reduced in the 2011 ESC. The 2011 ESC identified and used discrete lithofacies units to characterise the shallow geological environment. This approach moved away from the stratigraphic approach used in the 2002 PCSC, placing a greater emphasis on the descriptive analysis of the sequence. This allowed an improved understanding of the hydrogeological environment.</p> <p>GEO_006.3 - Issue not relevant No ternary diagrams or summary particle size distribution data are presented in the 2011 ESC. These are not used in the lithological classifications (Michie et al. 2010).</p> <p>GEO_006.4 - Issue closed The 2011 ESC incorporated information gained from ongoing investigations into characterising the Quaternary geological and sea level change sequences (Fish et al. 2010). Information on late glacial sea level change was used to understand</p>

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		relation to the regional framework.	geological reinterpretation of the LLWR site and its setting with respect to the Regional geology as described by the British Geological Survey.	<p>sea level change sequences and the generation of the Drigg spit feature. Additional dating of peat features within the geological sequence has been used to gain an understanding of the localised geological sea level changes. It was concluded that past sea level change information could not be used as an analogue for future sea level changes around the repository site.</p> <p>The use of geophysical investigations across and along the Drigg dunes has greatly increased the understanding of the nature of the Quaternary geology (Halcrow 2010).</p>
GEO_007	Adequacy of information / referencing – geochemical characterisation	<p>GEO_007.1 Ensure that the tritium data derived from monitoring results are referenced back to their source, and assessed for quality in the same manner as the other BNFL site characterisation data and Nirex data.</p> <p>GEO_007.2 Reference the source of thermodynamic data used in speciation and mineral saturation calculations in the Geochemical Interpretation.</p> <p>GEO_007.3 Document the procedures for entering all historical and</p>	<p>GEO_007.1 all parts – In hand or planned for the 2011 ESC</p> <p>Referencing and quality of data used in the 2011 ESC will be addressed as described in the ESC approach document (Baker et al. 2008).</p>	<p>GEO_007.1 and GEO_007.3 - Issues closed</p> <p>From 2008 a comprehensive database was set up by LLW Repository Ltd to contain all environmental monitoring data and aid a consistent approach to data access and processing, management, quality control issues and programme definition (Monitor Pro 5). Checked and validated historical groundwater quality data are being added retrospectively (LLW Repository Ltd 2011b). Quality assured data from this database have been used to inform the hydrogeological model (Hartley et al. 2011a).</p> <p>We carried out an audit in 2011 that examined the generation, storage and transfer of geological and environmental information used to support the 2011 ESC (Clarke 2011). The audit did not find any issues and confirmed that the systems in place were robust and</p>

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		future site characterisation data used to support the PCSC into the BNFL site characterisation database.		<p>comprehensive.</p> <p>GEO_007.2 - Issue not relevant</p> <p>Detailed speciation and mineral saturation calculations are not carried out in support of the 2011 ESC.</p>
GEO_008	Adequacy of information / referencing – retardation characterisation	<p>GEO_008.1</p> <p>Provide the series of BNFL Internal Reports that support the derivation of the Drigg sorption database for the geosphere. The information to be provided should include the sorption data used, should allow the quality of the data to be evaluated, and should include a list of excluded data.</p> <p>GEO_008.2</p> <p>Justify the selection of the data used for modelling sorption in the Ormskirk sandstone.</p>	<p>GEO_008.1 and GEO_008.2 – Accepted / work done plus planned for the 2011 ESC</p> <p>Randall (2008) provides a recent justification of the sorption parameters used in the Requirement 2 assessment calculations. We will consider the need for further review, referencing or data compilation prior to the 2011 ESC.</p>	<p>GEO_008.1 and GEO_008.2 - Issues closed</p> <p>Issues closed with reference to Randall (2008) and Kelly et al. (2011). Recommendations relating to the derivation of the geosphere sorption database and treatment of uncertainty are covered under GEO_016.2 and GEO_016.3.</p>
GEO_009	Screening, model development and assumptions - geological issues	<p>GEO_009.1</p> <p>Provide further quantified justification for the use of the MODFLOW model to describe flow within the Regional Groundwater, in the light of the more recent conceptual model for groundwater flow.</p> <p>GEO_009.2</p>	<p>GEO_009.1 – Superseded</p> <p>These comments relate to the approach pursued in the 2002 PCSC and have been superseded.</p> <p>GEO_009.2 – Accepted / in hand or planned for the 2011 ESC</p> <p>Arthur et al. (2008) describes</p>	<p>GEO_009.1 - Issue not relevant</p> <p>Issue now superseded.</p> <p>GEO_009.2 - Issue closed with recommendation</p> <p>Jackson (2011) acknowledges that flow in the upper sandstone makes a significant contribution to regional groundwater flow. Flow in the sandstone is considered in the hydrogeological model, using regional hydraulic conductivity</p>

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		<p>Further justify the use of 'appropriate parameters' within the network model to account for groundwater flow in the sandstone below the north-western part of the site in certain future scenarios.</p> <p>GEO_009.3</p> <p>Provide evidence that the effects on future groundwater flow paths of migrating coastal dune fields (in the area between the site and the coast, and further inland) have been adequately accounted for in the risk assessment models.</p>	<p>the development of the 3D site-scale groundwater model using FEFLOW. The FEFLOW model has been used to derive the groundwater fluxes and associated pathway geometry required by the ESC Project safety assessment model.</p> <p>GEO_009.3 – Accepted / in hand or planned for the 2011 ESC</p> <p>Further development of the site-scale groundwater flow model is planned to ensure that potential effects on the groundwater pathway due to climatic changes or coastal erosion are considered.</p>	<p>data. As discussed in GEO_023.1, there is no consideration of the relative importance of matrix flow compared with fracture flow in the upper Ormskirk sandstone.</p> <p>We understand that a study on the effect of faults on hydrogeology in the vicinity of the LLWR was carried out after submission of the 2011 ESC but we have not seen this work. We recommend that this work is incorporated into the hydrogeological conceptualisation (Recommendation SUE9).</p> <p>GEO_009.3 - Issue closed</p> <p>In our review of the 2011 ESC, we raised a query on the behaviour of the dune system during coastal erosion and sea level rise and the role of the underlying geology on the overall ESC (IRF ESC-TQ-SUE-022). In addition, as part of our work on the LLWR Habitats Regulations assessment (Environment Agency 2014), we sought clarification on the extent of any changes to the surface and groundwater system in the Drigg Dunes adjacent to the LLWR as a result of the development of the LLWR. This information, in addition to that presented within the 2011 ESC, adequately addresses this recommendation.</p> <p>The majority of the 2011 ESC hydrogeological and geological investigations and monitoring focused on the glacial drift geology. Information presented hypothesised that the shallow groundwater within the dune system (and potential future dunes) would be isolated from</p>

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				<p>the deeper Quaternary geologies (B3 unit).</p> <p>The dunes are located above the base of the low permeability glacial geologies between the repository and the beach. The geometry and discontinuous nature of the dune deposits mean that they cannot act as a viable groundwater pathway for discharges from the repository. The presence of the dunes may change the amount and rate of vertical recharge of the lower glacial geologies that form the main groundwater pathway. The majority of groundwater flow in the deeper geologies is derived from recharge zones significantly upstream (to the east) of the site.</p> <p>Based upon the evidence presented by LLW Repository Ltd we do not consider the Drigg Dunes as playing an important role in the groundwater migration pathways.</p>
GEO_010	Screening, model development and assumptions - hydrogeology issues	<p>GEO_010.1</p> <p>Develop a realistic continuum hydrogeological model, based on the stochastic descriptions of the geology and hydrogeology (see also GEO_002.2). Calibrate the model in both steady and transient states, for each stochastic realisation, and assess the effect of structural (that is, facies distribution) and parameter uncertainty. Use this model directly for the PCRSA, producing a set of</p>	<p>GEO_010.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>As mentioned under GEO_002 work has been carried out recently on alternative geological conceptual models (Serco 2008a) and further work is planned to determine whether a stochastic representation of the system can be developed. We would then determine how this model should be used to support the safety case. However, we</p>	<p>GEO_010.1 - Issue closed</p> <p>We consider that the approach taken to develop the 2010 hydrogeological model (comprising development of a calibrated ConnectFlow groundwater flow model and an equivalent GoldSim compartmental flow model (Hartley et al. 2011a) to be reasonable, providing a significant improvement over the 2002 model. Comments on the suitability and robustness of the hydrogeological model are provided in Environment Agency (2015b).</p>

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		alternative results (stochastic approach) and, if a network model is desired, develop the network model so that its results are consistent with each of the continuum model results.	consider the details of this recommendation to be disproportionate and question whether the proposed approach is the best way of enhancing confidence in the safety case.	
GEO_011	Screening, model development and assumptions - geochemical issues	<p>GEO_011.1 Introduce a stronger linkage between FEP screening, modelling assumptions, and derivation of parameter values, so that it is clear where and how FEPs are accounted for in models and parameter values.</p> <p>GEO_011.2 Clarify how the derivation of 'best-estimate' parameter values accounts for all of the FEPs that the parameter is purported to represent.</p>	<p>GEO_011.1 – Accepted / in hand or planned for the 2011 ESC</p> <p>We will review the list of FEPs prior to or as part of the 2011 ESC in order to ensure that they are treated appropriately or ruled out using appropriate arguments. This will result in an auditable trail.</p> <p>GEO_011.2 – Accepted / in hand or planned for the 2011 ESC</p> <p>No general justification can be provided. Where parameter choices in the 2011 ESC are intended to allow for some specific process, we will present the parameter-specific arguments.</p>	<p>GEO_011.1 and GEO_011.2 - Issues closed with recommendation</p> <p>This IAF relates to the fact that, in the 2002 PCSC, the retardation of a radionuclide in the geosphere was determined through a combination of a partition coefficient (Kd value) and the porosity and density of the medium through which it is flowing. No other geochemical processes were modelled explicitly within the geosphere transport model.</p> <p>The same approach was adopted in the 2011 ESC. Conceptual uncertainty in the use of Kd values to represent retardation is discussed in FEP GW_GEO_CM_MP RR M_07 (LLW Repository Ltd 2013); Kd values are chosen 'in line with almost all assessments' and no alternative models are considered. Although we are satisfied that the approach used is adequate, LLW Repository Ltd should keep a watching brief on future developments in the modelling of retardation (Recommendation SUE31).</p> <p>See also GEO_016.</p>
GEO_012	Screening, model	Sorption issues: See IAF GEO_011.	No additional recommendation.	GEO_012 - Issue closed

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	development and assumptions - retardation / organics / colloid issues	Colloids and humics: No action need be taken at present.		
GEO_013	Treatment of uncertainty - site characterisation , geology and hydrogeology	<p>GEO_013.1</p> <p>Discuss the effects of major (laterally restricted) high-permeability fast hydraulic pathways on the conceptual and numerical models for groundwater flow, and consider whether the measures adopted to accommodate smaller features of this type in the PCRSA models are adequate to describe and quantify larger-scale effects.</p> <p>GEO_013.2</p> <p>Provide explicit justification for the use of geometric mean values for hydraulic conductivities as the basis for 'best-estimate' measures for the hydrogeological behaviour of all drift formations.</p> <p>GEO_013.3</p> <p>Clarify, and address discrepancies in, its</p>	<p>GEO_013.1 and GEO_013.3 – Accepted / in hand or planned for the 2011 ESC.</p> <p>The development of a 3D hydrogeological model for the site as described in Arthur et al. (2008) and the update of the conceptual model (Henderson 2008a) has enabled further investigation of the potential groundwater pathways. Such preferential pathways are not considered to be the dominant mechanism for the release of contaminants from the site. Further consideration will be part of future work and relevant arguments will be set out as part of the 2011 ESC.</p> <p>GEO_013.2 – Accepted / in hand or planned for the 2011 ESC</p> <p>Justification and the linkage between modelling assumptions and data will be</p>	<p>GEO_013.1 - Issue closed with recommendation</p> <p>The 2011 ESC notes the potential for incised channels infilled with gravel within B3 to act as fast pathways. Jefferies (2009) states that the potential hydrogeological significance of the channels is still uncertain. According to Hartley et al. (2011a), hydrogeological information (low horizontal gradients and high hydraulic diffusivities) suggests that these channels are extensive, at least providing a rapid hydraulic connection between the shore and the site. Jefferies (2009) states that the impact of large-scale features such as channels could be treated deterministically in variant calculations to assess their potential impact on post-closure performance. However, this is not presented in the 2011 ESC, although increased flow rates in B3 are considered in the probabilistic groundwater pathway assessment calculations. We are satisfied that the potential effects of this phenomena are appropriately bounded within the current assessments but we recommend that further assessment is completed to determine the potential effect of incised channels acting as fast pathways (Recommendation SUE8).</p>

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		hydrogeological pathway analysis.	revised for the 2011 ESC.	<p>GEO_013.2 - Issue not relevant</p> <p>Certain hydrogeological parameters used in the 2010 hydrogeological model, including hydraulic conductivities, were defined through model calibration using site data, using parameter data from previous iterations of the model (2009 and 2010) as a starting point (Hartley et al. 2011a).</p> <p>GEO_013.3 - Issue not relevant</p> <p>Issue related to identified discrepancies in the documentation of the 2002 PCSC hydrogeological pathway analysis.</p>
GEO_014	Treatment of uncertainty - hydrogeological modelling	See GEO_010.1.	No additional recommendation.	GEO_014 - Issue closed
GEO_015	Treatment of uncertainty - geochemical issues	<p>GEO_015.1</p> <p>Present the analytical errors associated with the geochemical data, and document an assessment of whether these errors are significant to the hydrogeochemical interpretation.</p> <p>GEO_015.2</p> <p>Further constrain the variation in rainwater composition at the Drigg site in order to reduce uncertainty in detailed aspects of the hydrochemical</p>	<p>GEO_015.1 – Accepted / In hand or planned for the 2011 ESC</p> <p>Interpretation of the hydrogeochemical data in the 2011 ESC will take into account the range of errors associated with analytical testing and assess whether they are significant in terms of any interpretation derived from the use of the data.</p> <p>The environmental monitoring programme is designed to provide analytical data from</p>	<p>GEO_015.1 to GEO_015.4 - Issues closed with recommendation</p> <p>In this IAF we queried whether there is any present-day upward flow and mixing of saline groundwater from depth. Jackson (2011) states that groundwater salinity is very low because the system is an active near-surface system, with groundwater constantly being replenished by recharge of nearly fresh water from precipitation. In the vicinity of the coast it is expected that seawater would intrude into the groundwater system, but saline water would only be present near the surface for rocks offshore and within a very short distance of the coast. Although we are minded to agree with these statements, no</p>

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		<p>interpretation.</p> <p>GEO_015.3</p> <p>Review the dichotomy between averaging experimental data to obtain a 'best-estimate' and the assumption that the range in the experimental data captures uncertainty over the geochemical environment.</p> <p>GEO_015.4</p> <p>Present the assessment of the uncertainty associated with selection of a single groundwater composition for near-field performance.</p>	<p>accredited laboratories in which there can be a high degree of confidence.</p> <p>However, where analytical data are used in support of the 2011 ESC any uncertainty in the data will be presented.</p> <p>GEO_015.2, 15.3 and 15.4 – Accepted / In hand or planned for the 2011 ESC</p> <p>Treatment of uncertainty in the safety assessment is detailed in the safety assessment approach document. Our intent is to focus on those uncertainties that are most important in determining performance. We do not believe that the uncertainties identified in this IAF fall into this category.</p>	<p>evidence is provided in the 2011 ESC.</p> <p>No geochemical processes are modelled explicitly within the geosphere transport model in the 2011 ESC; the net effect of processes such as sorption and ion-exchange are captured using Kd values. However, unlike in the 2002 PCRSA, groundwater composition is not an input to the 2011 ESC models (other than its influence on contaminant sorption). Thus uncertainty and variability in the hydrochemical and mineralogical environment of the environs of the LLWR are not considered in the 2011 ESC.</p> <p>Whilst we consider the geochemical understanding sufficient to inform the 2011 ESC, we would like to see the forward programme include further work to improve site geochemical understanding (Recommendation SUE31).</p> <p>Also see GEO_003.9 and GEO_016.2.</p>
GEO_016	Geosphere sorption database derivation and treatment of uncertainty	<p>GEO_016.1</p> <p>Carry out a new systematic experimental study of uranium sorption in the Drigg sediment/groundwater system. Such a study should be guided by speciation and sorption modelling, and should concentrate on the effects on sorption of groundwater composition and fulvic acids.</p>	<p>GEO_016.1 – Accepted / Satisfied by work completed since 2002</p> <p>The LLWR has carried out an experimental study of uranium sorption, which reported this year (Dutton and Trivedi 2008).</p> <p>GEO_016.2 – Rejected / disproportionate</p> <p>Sorption in the geosphere is</p>	<p>GEO_016.1 – Issue closed</p> <p>LLW Repository Ltd has carried out sufficient investigations since 2002.</p> <p>GEO_016.2 – Issue closed with recommendation</p> <p>The significance of uranium and its daughter radionuclides as a contributor to groundwater pathway risk in the long-term is diminished in the 2011 ESC compared with the 2002 PCSC. Peak radiological impacts for the groundwater</p>

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		<p>Note that the sediment contains sorbed organics which may desorb if organic-free groundwater is used. It is also important that colloids should remain with the solid phase when the phases are separated (some of the older data sources in BNFL (2003b) used 0.2 or 0.45 micron filters or short centrifugation times at slow speeds - this can result in 'low' Rd values). Groundwater composition should be measured before, during and after sorption (probably in radionuclide-free experiments), and the sediment used should be fresh, that is, stored for a minimum time under in situ conditions and not dried.</p> <p>GEO_016.2</p> <p>Radionuclides other than uranium should be included in the above study where their sorption properties (Kd values) could significantly affect the safety case. In particular, elements in the U-234 decay chain could usefully be included in the above experimental programme. The</p>	<p>not likely to be a significant control on the radiological impacts arising for the water abstraction well and therefore such studies are not considered a priority.</p> <p>GEO_016.3 – Accepted / In hand or planned for the 2011 ESC</p> <p>As noted above, we have recently re-assessed available far-field sorption data. We will consider the need for further review, referencing or compilation of far-field sorption data prior to the 2011 ESC. This will include consideration of the use of data from different sorts of experiment and their application to longer lengthscales.</p> <p>GEO_016.4 – Accepted / In hand or planned for the 2011 ESC</p> <p>We will record where and how expert judgement has been used as part of the data management process in the 2011 ESC.</p>	<p>pathway, in particular for the well pathway, for which highest impacts are calculated, are dominated by C-14, Cl-36 and I-129 and, to a lesser extent, Pb-210 and Pu-239. The quality of geosphere Kd data for these risk-dominating radionuclides is variable. In particular, there are no site-specific Kd data for lead and site data for plutonium recommended by Randall (2008) are rejected on the basis of being too low by Kelly et al. (2011).</p> <p>The effect of uncertainty in geosphere sorption coefficients is considered in the probabilistic GoldSim assessment model; for the B2 and B3 units the assumed maximum and minimum values of plus and minus one order of magnitude from the best estimate. We note that this is insufficient to capture the full uncertainty around Kd values for some species.</p> <p>Although we consider that the 2011 ESC approach to the assessment of retardation in the geosphere is appropriate in terms of the use of Kd values to represent retardation and in selection of Kd data, we recommend that LLW Repository Ltd's forward programme includes further substantiation of Kd data, to demonstrate that the selected Kd data are consistent with site conditions, and review of any future developments in the modelling of retardation (Recommendation SUE31).</p> <p>GEO_016.3 – Issue closed with recommendation</p> <p>We are content with the level of conservatism</p>

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		<p>limited data for Th, Ra and Pb means that the experimental variation is not observed to the same extent as for uranium; this gives a false sense of confidence in the Kd value, based on data scarcity rather than real sensitivity.</p> <p>GEO_016.3</p> <p>Develop an improved treatment of upscaling of sorption measurements, either by including the effects of organics and colloids when modelling column experiments and/or by more realistic field studies.</p> <p>GEO_016.4</p> <p>Show clearly where and how expert judgement has been used and on what basis chemical analogues have been selected for the sorption database.</p>		<p>present in the geochemical parameters used in the 2011 ESC geosphere models, but recommend that the forward programme includes further substantiation of Kd data to demonstrate that Kds are consistent with site conditions and review any future developments in the modelling of retardation. This might include consideration of upscaling of sorption measurements and should be included in the work programme discussed above. Site-derived information should be used where possible (Recommendation SUE31).</p> <p>GEO_016.4 - Issue closed</p> <p>Accepted with reference to Randall (2008) and Kelly et al. (2011).</p>
GEO_017	Climate change effects on hydrogeology	<p>GEO_017.1</p> <p>Analyse an increase in recharge scenario for the regional groundwaters, and a low recharge scenario for a totally forested site.</p>	<p>GEO_017.1 – In hand or planned for the 2011 ESC</p> <p>The 2011 ESC will use recharge values that reflect the range of possible climate evolution scenarios for the site.</p>	<p>GEO_017.1 - Issue closed with recommendation</p> <p>The shorter assessment timescales until site destruction considered in the 2011 ESC compared with the 2002 PCSC reduce the importance of this issue as originally presented. An updated assessment of baseflow (and</p>

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		<p>GEO_017.2</p> <p>Link the narrative descriptions of site evolution with continuum hydrogeological modelling of the responses to climate change in order to calibrate the PCRSA modelling over time.</p>	<p>GEO_017.2 – In hand or planned for the 2011 ESC</p> <p>The 2011 ESC will provide a clear link between the scenarios selected and the narrative descriptions of site evolution.</p>	<p>implications on recharge and water balance) is presented in Henderson (2008b). However, prior to the assumed disruption of the site by coastal erosion, it is assumed that there will be a period of warming climate and sea level rise. The implications of these changes are incorporated as a 13% increase in HER from 2080 and increasing heads in the regional groundwater in the hydrogeological model (Hartley et al. 2011a). Implications on recharge and baseflow are not considered. Also, the 13% increase in HER is not substantiated; instead reference is made to a memo by Thorne (2010) that is not included in the 2011 ESC submission. Given that 'by 2100 the projected global temperature rise is 1.1 to 6.4 °C (relative to 1980 to 1999)' (LLW Repository Ltd 2011c), potential implications on hydrogeological parameters other than just heads and HER should be considered in future assessments. We are satisfied with the evidence presented in the 2011 ESC, but have recommended that the effects of increased storminess and the amount of precipitation should also be further considered in the future. It is recommended that shorter term climate change trends (<100 years into the future) are used to inform longer term recharge values (Recommendation SUE38).</p> <p>GEO_017.2 - Issue closed</p> <p>The relatively short assessment timescale considered within the 2011 ESC means that there is a lesser requirement for narratives of the evolving landscape as climate change during the</p>

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				<p>period of assessment is less extreme than considered in 2002.</p> <p>LLW Repository Ltd developed assessment scenarios and carried out modelling of the anticipated form and timing of coastal erosion taking account of the likely changes in sea level and the physical properties of the eroding materials in the 2011 ESC. The company superimposed the expected coastal recession rate on to the hydrogeological model in order to ensure that the location of groundwater discharge reflected the expected cliff recession.</p>
GEO_018	Planning and adequacy of site monitoring programme – hydrology and hydrogeology	<p>GEO_018.1</p> <p>Ensure, as a priority, the systematic collection of further time-series hydro-data (water flow parameters, water quality and contaminant analyses) from both the site and off-site area. See also GEO_022.2.</p> <p>GEO_018.2</p> <p>Specify the principles and practices adopted in defining the baseline hydrogeological and geological conditions for comparison with future situations.</p>	<p>GEO_018 – Accepted / In hand or planned for the 2011 ESC</p> <p>The environmental monitoring programme for the site has been designed to provide the data required for 2011 ESC including time series data sets.</p> <p>Baseline hydrogeological conditions are defined taking into account the range of values observed as part of the site monitoring programme taking into account seasonal fluctuations and any definable trends.</p> <p>Geological conditions are defined from borehole, trial pits and field exposures. A 3D geological model of the site</p>	<p>GEO_018.1 - Issue carried through to ESC-FI-005</p> <p>We appreciate that LLW Repository Ltd has made significant effort in terms of environmental monitoring of the site, including use of the Stage 6 off-site boreholes and the updated site monitoring programme. However, as stated in the Level 2 assessment of long-term radiological impacts, 2 of the 5 identified 'key uncertainties' in the assessment relate to 'the effective dilution factor of water entering the Regional Groundwater from the repository, linked to the degradation of the engineered features; and uncertainties related to the heterogeneous nature of the Quaternary sediments and consequent flow path characteristics and dilution'.</p> <p>We understand that the use of monitoring data to reduce uncertainties relating to the dilution of contaminant concentrations in the groundwater</p>

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			<p>has been developed which will be updated as new data become available.</p>	<p>is being considered (Baker and Cummings, 2012). This issue was picked up in IRF ESC-RO-SUE-007. Although this IRF has been closed, we consider that the collection of further data (hydrological, hydrogeological and contaminant analysis) targeted to reducing these uncertainties should be carried out. This issue is being taken forward via ESC-FI-005.</p> <p>GEO_018.2 - Issue closed with recommendation</p> <p>LLW Repository Ltd extensively used information from its monitoring programme in the preparation of the 2011 ESC, including an assessment of baseline conditions. However, given that the LLWR has been discharging to the environment over an extended period, the development of baselines is difficult.</p> <p>For future disposals to the vaults, monitoring might provide an indication of the pre-disposal environmental conditions, but environmental impacts from the trench disposals will need to be taken account of.</p> <p>LLW Repository Ltd has been able to identify the nature and extent of, and changes in, radioactive discharges from the trenches and to project the evolution of future discharges from the trenches. Monitoring information from around the trenches has been used, and should be used in the future, to underpin future management options.</p> <p>LLW Repository Ltd carried out a non-radiological hydrogeological risk assessment as</p>

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				<p>part of the 2011 ESC. This information has been used to generate baseline and compliance levels for non-radiological substances (Speed and Fretwell 2011).</p> <p>We note that a significant proportion of groundwater and other environmental monitoring points do not show any impact from the repository. LLW Repository Ltd should continue to carry out baseline monitoring and characterisation for new vaults. Information from this monitoring should be used to determine the ongoing performance of the new vaults (Recommendation SUE11).</p>
GEO_019	Characterisation for construction and minimisation of geological disturbance during construction	GEO_019.1 In advance of construction of Vault 9, provide detail of what ground conditions are specified in the design envelope for Vault 9, how these conditions assure that the geology and hydrogeology assumed in the PCRSA are met, and how alternative designs might be assessed for implementation in the case of conditions not being met. Also provide detail of the investigations that will be conducted in advance of, or during, construction to assess the conditions.	GEO_019.1 and GEO_019.2 – Satisfied by work completed since 2002 A detailed site investigation programme was implemented to provide ground condition data to support the Vault 9 design. Further observations have been made during the construction of Vault 9 to provide further confirmation of the predicted conditions.	<p>GEO_019.1 and GEO_019.2 - Issues closed with recommendation</p> <p>The issue is closed with regard to the construction of Vault 9. The 2011 ESC hydrogeological model takes account of the impact of future vault construction on groundwater recharge, the relative depth of the unsaturated zone and contaminant migration flux and direction.</p> <p>However, there is a continuing need to consider the effect of future vault construction on localised flows and geological properties, for example with respect to creation of preferential contaminant migration pathways. Similarly, uncertainty caused by the difference between the predicted and actual geology around future vaults will need to be considered.</p> <p>We recommend that LLW Repository Ltd</p>

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		GEO_019.2 Provide an improved FEP analysis of potential disturbance by site investigation, excavation/construction, and repository sealing activities.		monitors the effects of the construction of future vaults on contaminant migration and the behaviour of the existing trench contamination plume throughout the construction and restoration sequence (Recommendation SUE11). We expect information from future site investigations and geological observations to be used to inform future updates of the ESC.
GEO_020	Demonstration of multi-barrier concept	There are no recommendations.	No response required.	GEO_020 - Issue closed
GEO_021	Implications of data freeze	GEO_021.1 Document the data freeze points applied in the 2002 PCSC, identify and present data that have been collected since the data freeze, and present an evaluation of the potential significance of these data to PCRSA results. GEO_021.2 Present the procedures in place to regularly review site characterisation data arising after data freeze points and to deal with new data that affect or contradict PCRSA modelling approaches or parameter values.	GEO_021 – No longer relevant or rejected A datafreeze is essential as a starting point for an assessment or Environmental Safety Case. All data sets to be used in the 2011 ESC will be frozen in advance of the assessment. If new data that become available after the datafreeze, are significantly different or cast doubt on the ESC, then this would be considered and appropriate action identified. LLW Repository Ltd has no specific procedure of the sort identified, but we will provide appropriate comment in the 2011 ESC, indicating any significance of	GEO_021.1 and GEO_021.2 - Issue closed The Level 2 Hydrogeology report (LLW Repository Ltd 2011d) notes that a data freeze of April 2010 was implemented 'to ensure that analysis was based on a defined dataset'. We would not expect LLW Repository Ltd to assess the implications of data collected after the data freeze in the 2011 ESC. However, we expect the company to regularly review its monitoring data to ensure consistency with ESC assumptions.

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			data collected subsequent to the datafreeze. We do not however propose to present those data systematically in the 2011 ESC.	
GEO_022	Documentation of the site characterisation programme	<p>GEO_022.1</p> <p>Provide detailed information on the following:</p> <ul style="list-style-type: none"> (1) core-recovery data for all boreholes penetrating drift formations used in the risk assessment, together with an account of the geological and hydrogeological significance of such data; (2) the sampling methods used, and the distribution of samples obtained, from boreholes and other exposures for use in hydraulic conductivity testing; and (3) the techniques used to calibrate, process and filter signals obtained during studies using ground-penetrating radar, MRT and down-hole geophysical logging. <p>GEO_022.2</p> <p>Ensure, as a priority, the systematic collection of further</p>	<p>GEO_022.1 – Accepted / satisfied by work completed since 2002</p> <p>Smith (2007) provides a summary of the site investigation works that have been carried out since 2002 that have targeted both the Ormskirk Sandstone and the drift deposits. Where geological data are used to support the 2011 ESC the source of the data will be fully referenced and the limitations of core recovery and sampling methods used will be considered.</p> <p>GEO_022.2 – Accepted / satisfied by work completed since 2002</p> <p>Systematic collection of time series hydrological and hydrogeological data has been instigated since 2002 to aid the understanding of the site water balance. These data have been used to update the site</p>	<p>GEO_022.1 - Issue closed</p> <p>Three major series of site investigations have taken place since 2008: the Vault 9 investigations (Smith 2009b), Stage 6 boreholes (URS 2009) and the coastal geophysics investigations (Halcrow 2010).</p> <p>We gained confidence in the appropriateness and robustness of core recovery and soil and environmental sampling prior to the submission of the 2011 ESC. We are satisfied that LLW Repository Ltd used appropriate site investigation techniques, suitably qualified and experienced personnel (SQEP) and British Standard logging/sampling methodologies where appropriate.</p> <p>Calibration techniques for the geophysical investigation are reported by Halcrow (2010). In addition, information derived from site investigation boreholes was used to calibrate geophysical profiles and to assist in the interpretation of outputs.</p> <p>GEO_022.2 - Issue closed with recommendation</p> <p>LLW Repository Ltd has obtained a significant quantity of new data (both on and off site) since 2002, which it used to update the site water</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comment on LLW Repository Ltd's position
		<p>time-series hydrological and hydrogeological data, with special reference to:</p> <p>(1) site water balance calculations; and</p> <p>(2) hydraulic properties of the Ormskirk Sandstone (including fractures) and deeper drift formations in on-site and off-site areas.</p>	<p>water balance (Towler et al. 2007) and identify areas where further monitoring will be undertaken to support the 2011 ESC.</p> <p>Boreholes into the Ormskirk sandstone and deeper drift deposits have been constructed since 2002 and have been used to assess hydraulic properties of the strata. Further boreholes are planned off-site, which are designed to provide further information on the hydraulic properties of both the Ormskirk sandstone and the drift deposits as described in the updated conceptual model report (Henderson 2008a).</p>	<p>balance (Towler et al. 2007) and estimate baseflow (Henderson 2008b). Because of the remaining levels of uncertainty in the geological and hydrogeological properties of the LLWR and environs, we recommend that further systematic collection of hydrological and hydrogeological data should be carried out as part of the routine monitoring programme to allow future refinements where possible (Recommendation SUE7).</p>
GEO_023	Characterisation of contaminant plumes	<p>GEO_023.1</p> <p>Monitor for contamination entering the sandstone beneath the site, and determine if the flow in the sandstone is dominated by fracture flow or by matrix properties.</p>	<p>GEO_023.1 – Accepted / In hand or planned for the 2011 ESC</p> <p>Contaminant levels in the sandstone have been monitored as part of the site investigation work since 2002. Flow in the sandstone has been investigated as part of the site scale modelling work (Arthur et al. 2008). The hydraulic gradients in the</p>	<p>GEO_023.1 - Issue closed with recommendation</p> <p>Hydraulic conductivities in the upper sandstone (regional data) are similar to those measured in Quaternary deposits at the LLWR (Jackson 2011) and flows are near-horizontal. Although new boreholes have been drilled into the upper Ormskirk Sandstone, no data are presented in the 2011 ESC that indicate the proportion of contamination reaching the upper sandstone. Although 'hydraulic communication with the Ormskirk Sandstones is expected to be limited</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comment on LLW Repository Ltd's position
			<p>deeper drift deposit and the Ormskirk Sandstone indicate that flow is predominantly horizontal with vertical gradient reducing with depth as such contaminant transport from the site is considered to be predominantly be within the drift deposits. New off-site boreholes are planned to provide more information on the contaminant movement within the sandstone with both analysis of the groundwater for contamination and hydraulic testing.</p>	<p>due to the intervening semi-permeable lithofacies unit C' (Hartley et al. 2011b), there appears to be a potential for some flow between the sandstone and unit B3. LLW Repository Ltd (2013) states that regional groundwater pathway consists of quasi-lateral flow through the superficial deposits and upper sandstone, and that the maximum depth of the regional pathway is a principal uncertainty. We recommend that LLW Repository Ltd reviews the relative importance of fracture flow versus matrix flow in the upper sandstone (Recommendation SUE9). As noted by Michie et al. (2010), the Ormskirk Sandstone is likely to exhibit significant fracture porosity.</p> <p>We also understand that, post-submission of the 2011 ESC, LLW Repository Ltd has carried out an assessment of the effect of faults on the hydrogeology in the vicinity of the LLWR. We have not seen this work, but would expect it to be incorporated into future conceptualisations (also included in Recommendation SUE9).</p>
GEO_024	Specific modelling issues	<p>GEO_024.1 Further justify or revise the modelling approach to representation of a well for water extraction.</p> <p>GEO_024.2 Further justify or revise the screening-out of diffusion through the cut-off wall.</p>	<p>GEO_024.1 – Accepted / In hand or planned for the 2011 ESC</p> <p>Further work on the representation of water abstraction wells has been carried out (Serco 2009) and will be continue to be developed in conjunction with the refinement of the site-scale</p>	<p>GEO_024.1 – Issue closed - subsumed into IRFs ESC-TQ-ASO-009 and ESC-TQ-ASO-009a</p> <p>We accept that LLW Repository Ltd has significantly developed its approach to the representation of radiological impacts associated with the well pathway in the 2011 ESC. We raised a number of queries on these calculations in IRFs ESC-TQ-ASO-009 and ESC-TQ-ASO-009a, which were addressed to our satisfaction.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comment on LLW Repository Ltd's position
		<p>GEO_024.3</p> <p>Re-estimate the HER in the forested areas of Drigg, and improve the calibration of the water balance model.</p>	<p>groundwater model.</p> <p>GEO_024.2 – Accepted / In hand or planned for the 2011 ESC</p> <p>Further work is planned to consider the representation of the engineering structures as part of the 2011 ESC. We would be able to confirm for suitable choices of parameters that advective fluxes dominant over diffusive fluxes.</p> <p>GEO_024.3 – Accepted / In hand or planned for the 2011 ESC</p> <p>Further work has been carried out on both the site water balance (Towler et al. 2007) and the calculation of HER using the WATBAL model (Henderson and Whitaker 2008). Henderson and Whitaker (2008) take into account the land use of different areas of the site including the effects of trees on effective rainfall. Since 2002 a significant area of the site has been cleared of the trees and this has been incorporated into the HER calculations.</p>	<p>GEO_024.2 – Issue closed with recommendation</p> <p>Rough calculations presented in GEO_024 indicated that the effects of diffusion through the cut-off wall could be significant.</p> <p>We note that the function of the cut-off wall in the 2011 ESC engineering design is different to the 2002 PCSC design. The primary role of the cut-off wall is initially to minimise groundwater ingress into the repository and deflect groundwater vertically downwards. Over an extended timeframe, the cut-off wall may contain contaminated groundwater and direct it downwards.</p> <p>The 2011 ESC does not address diffusion through the engineered barriers. Uncertainties in the performance of the cut-off wall are presented in terms of predicted hydraulic conductivities (Jackson et al. 2011). We consider it probable that advective fluxes are dominant over diffusive fluxes. However, if the cut-off wall cracks or physically degrades then it is reasonable to assume significant increases in advection through the faults. This should be substantiated with reference to existing literature (Recommendation O&E12).</p> <p>GEO_024.3 – Issue closed</p> <p>Response accepted; substantiation for the value of HER used in the ESC is covered in PAR_005.1.</p>

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11. Appendix 6. BIO IAFs

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
BIO_001	Biosphere adequacy of information / referencing	<p>BIO_001.1 Provide a more detailed description of the current biosphere in support of the development of the biosphere model.</p> <p>BIO_001.2 Include an evaluation of the biosphere data for agro-climatic analogues and use such data to illustrate the range of parameter values that may be employed in the PCRSA.</p> <p>BIO_001.3 Map the FEPs to the Parameter Input Forms in order to provide traceability through the PCRSA.</p>	<p>BIO_001.1 – Rejected / not needed</p> <p>More detailed description of the biosphere would be relevant mainly in relation to present day exposures. We do not, however, consider additional data are needed in order to assess doses to currently exposed groups. In the longer term and especially in the period after authorisation, more stylised representations are appropriate as suggested in the draft near surface GRA. An exception is that we are seeking information on the use of wells locally in order to assess the likelihood of future agricultural or domestic wells.</p> <p>BIO_001.2 – Not needed / no longer relevant</p> <p>The BIOMASS reference biosphere approach implies using appropriate local and analogue data. The data for this have been reviewed, and reference parameters set out by Thorne (2007). The focus is</p>	<p>BIO_001.1 – Issue closed We accept that a 'more detailed description' of the present-day biosphere may not be necessary for short-term assessments. However, data on local conditions, for example soil type, would support the developing ESC and assist in reducing uncertainty in site understanding. We consider that the current site environmental monitoring programme is sufficient for the ongoing collection of site-specific biosphere data. See also our response on BIO_012.1 and Environment Agency (2015a).</p> <p>BIO_001.2 – Issue closed We agree that the shortened assessment timescale makes this recommendation less important. We also accept that human habit data need not be sampled stochastically. Some consideration of the ranges of parameter values is likely to be necessary to support arguments that the selected values are appropriate, but we accept that Thorne (2007, 2009) provides sufficient information for this purpose. See also our response on BIO_002.1.</p> <p>BIO_001.3 – Issue closed with recommendation The recommendation as expressed may not be</p>

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			<p>now on the period up to 5000 years making alternative agro-climatic analogues less relevant. We do not consider that it is appropriate to sample across consumption data or other human-habit related factors.</p> <p>BIO_001.3 – No longer relevant</p> <p>We are proposing a more direct approach to demonstrating inclusion of FEPs in scenarios and models for the 2011 ESC, see section 5.3.3 on FEPs in (Baker et al. 2008).</p>	<p>relevant, but we expect the documentation to make clear which FEPs are represented by which equations or parameters in models. FEPs relevant to the description of the biosphere and PEGs are included in the FEP and uncertainty tracking system (LLW Repository Ltd 2013), which provides links to documents providing more detailed descriptions of data and sources (Thorne 2009; Kelly et al. 2011). However, we note that whilst an audit of the 2011 ESC FEP list against the gas pathway calculations for C-14 and radon has been carried out (Limer et al. 2011; Limer and Thorne 2011), no such audit has been prepared for the groundwater, human intrusion or coastal erosion pathways. This would have been a useful addition (Recommendation ASS26).</p> <p>Also see our responses to COR_015.1 and BIO_003.4.</p>
BIO_002	Biosphere screening, model development and assumptions	<p>BIO_002.1 Justify the modelling of compartments and the compartment sizes used in the Biosphere Model during each system state. In particular, the compartments for Drigg coastal land, beach, foreshore and local coastal waters need to be justified and explained.</p> <p>BIO_002.2 Provide documentation on the</p>	<p>BIO_002.1 – Accepted / Work planned.</p> <p>Accepted. Additional attention will be paid especially in the context of impacts through coastal erosion. Work is planned in this area, see section 5.9 on coastal erosion in (Baker et al. 2008).</p> <p>BIO_002.2 – No longer relevant</p> <p>We are proposing a more</p>	<p>BIO_002.1 – Issue closed with recommendation</p> <p>We note that the groundwater pathway biosphere compartment model for the marine environment is virtually unchanged to that used in the 2002 PCSC. Updated compartmental models have been defined and substantiated for well, stream and estuary pathways (Thorne et al. 2010). Similarly, transfers between compartments are documented and substantiated. However, no further substantiation for the marine compartmental model is provided. Furthermore, discrepancies</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>decisions and assumptions used in identification and categorisation of the FEPs by the Biosphere Clearing House, including those FEPs which were eliminated from consideration in the PCRSA.</p> <p>BIO_002.3</p> <p>Provide thorough documentation on the treatment of FEPs. In particular, BNFL should map the FEPs listed in the appendices to the process system report to the appropriate CMU form.</p>	<p>direct approach to demonstrating inclusion of FEPs in scenarios and models for the 2011 ESC, see section 5.3.3 on FEPs in (Baker et al. 2008).</p> <p>BIO_002.3 – No longer relevant</p> <p>As above.</p>	<p>were observed between the groundwater pathway and the coastal erosion pathway marine biosphere models. This observation was taken forward in IRF ESC-TQ-ASO-003. Although LLW Repository Ltd provided adequate reasons for the most significant discrepancies between the groundwater pathway and the coastal erosion biosphere models in response, we recommend that there should be a greater correlation between the biosphere models for different pathways in future ESCs. Significant differences should be substantiated and implications on radiological impact identified (Recommendation ASS21).</p> <p>BIO_002.2 and BIO_002.3 - Issues closed</p> <p>We accept that the specific recommendations are no longer relevant. LLW Repository Ltd derived a new FEP list for the 2011 ESC that was based on the models that were proposed for use in the 2011 ESC, which were in turn based on experience and the results of previous assessments. A description of the FEPs, associated uncertainties and treatment in the ESC is provided in LLW Repository Ltd (2013).</p>
BIO_003	Biosphere Treatment of Uncertainty	<p>BIO_003.1</p> <p>Undertake an evaluation of the results of the PCRSA to understand how the key uncertainties relate to the most significant pathways and to focus the uncertainty analysis on the conceptualisation of the</p>	<p>BIO_003.1 and BIO_003.2 – Largely rejected / disproportionate</p> <p>We consider that investigation of uncertainties should focus on those cases that are both realistic and potentially challenge regulatory guidance</p>	<p>BIO_003.1– Issue closed</p> <p>The FEP and uncertainty tracking system lists the uncertainties in each biosphere FEP, classifies their significance and details how they have been treated in the ESC. LLW Repository Ltd also identifies its level of contentment with the treatment of the uncertainty and whether further assessment is required to reduce</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>process system during the states when the most significant doses occur.</p> <p>BIO_003.2</p> <p>Undertake a more thorough uncertainty analysis of currently omitted CMU topics, or provide a more rigorous justification for omitting uncertainties in heterogeneities within the biosphere, accumulation of contaminants, livestock husbandry and agricultural practices, and native/wild animal and plant populations.</p> <p>BIO_003.3</p> <p>Develop a clear presentation and audit trail of their uncertainty analysis.</p> <p>BIO_003.4</p> <p>Map modelled FEPs (including subsumed FEPs) to terms in the mathematical equations used in the BIOS, DEGAS and AMBER models.</p>	<p>levels. Cases that have low credibility, that is the key uncertainty concerns their occurrence, may be examined as 'what-if's in a less exhaustive fashion even if high conditional doses are implied.</p> <p>In addition, we consider that details of human habits and food-chain uptake parameters should be excluded from uncertainty analysis since this information relates to the uncertainties that are irreducible and cannot contribute to decisions on facility design or disposal practice</p> <p>Our approach to the treatment of uncertainty in general and also to biosphere uncertainties is set out in the sections 5.4 and 5.6 in (Baker et al. 2008).</p> <p>BIO_003.3 and BIO_003.4 – General issues / to be addressed in 2011 ESC</p> <p>These are general issues. Our approach to the treatment of uncertainty in general and to FEP audit is contained sections 5.4 and 5.3.3 in (Baker et al.</p>	<p>uncertainties. LLW Repository Ltd considers that uncertainty in the majority of relevant biosphere FEPs is low and that uncertainty has not been considered in the assessment. Of greatest significance is uncertainty in the coastal and marine environment, which is considered to be high but adequately treated in the ESC.</p> <p>Also see our response on COR_020.</p> <p>BIO_003.2 – Issue closed - subsumed into IRF ESC-RO-ASO-004</p> <p>A detailed description of the biosphere models used in the 2011 ESC is given in Thorne et al. (2010). However, there appears to be no systematic consideration of uncertainty in selecting and substantiating parameter values for deterministic calculations. None of the variant deterministic calculation cases nor the probabilistic simulation supporting the groundwater pathway consider uncertainty in any biosphere parameters. This issue has been subsumed into IRF ESC-RO-ASO-004. Although LLW Repository Ltd appropriately addressed the issues raised in this RO, we have raised ESC-FI-008 to seek a more traceable assessment of uncertainty associated with key ESC assumptions.</p> <p>Also see our response on COR_020.</p> <p>BIO_003.3 – Issue closed - subsumed into IRF ESC-RO-ASO-004</p> <p>Uncertainty in biosphere FEPs is discussed in LLW Repository Ltd (2013) and the significance</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
			2008).	<p>of this uncertainty and its treatment are detailed. Descriptions are at a fairly high level and linkages are made to supporting documents for data (for example Kelly et al. 2011 and Thorne 2008a). This issue has been subsumed into IRF ESC-RO-ASO-004, which, as discussed above, has been appropriately addressed.</p> <p>Also see our response on COR_020.</p> <p>BIO_003.4 – Issue closed with recommendation</p> <p>Different models are used in the 2011 ESC to the 2002 PCSC, but we expect the documentation to make clear which FEPs are represented by which equations or parameters in whatever models are used. LLW Repository Ltd (2013) provides a linkage between FEPs and the scenarios and pathways of the safety assessment. Links are given to supporting documents in which the models are described. We note that whilst an audit of the 2011 ESC FEP list against the gas pathway calculations for C-14 and radon has been carried out (Limer et al. 2011; Limer and Thorne 2011), no such audit has been prepared for the groundwater, human intrusion or coastal erosion pathways. This would have been a useful addition (Recommendation ASS26).</p> <p>Also see our responses to COR_015.1 and BIO_001.3.</p>
BIO_004	Environmental radioactivity	BIO_004.1 Undertake a sampling and	BIO_004.1 – Partly accepted, to be considered in the 2011	BIO_004.1 – Issue closed with recommendation

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>monitoring campaign to establish background levels of radioactivity in and around the Drigg site.</p> <p>BIO_004.2</p> <p>Make a full assessment of the potential increases in environmental radionuclide concentrations that includes all of the radionuclides considered in the PCRSA.</p>	<p>ESC.</p> <p>We consider that we have an understanding of background levels of radioactivity based on extensive surveys carried out in relation to Sellafield and to LLWR. This information is useful to provide general context and in relation to understanding a baseline for monitoring.</p> <p>BIO_004.2 – Partly accepted, to be considered in the 2011 ESC.</p> <p>This is part of the calculations needed to assess dose to human and to non-human biota. An assessment against base-line levels could be informative for some, for example natural, radionuclides and will be considered in the 2011 ESC.</p> <p>General comment</p> <p>The new near surface GRA sets a different requirement in the area of environmental activity area, focusing on potential for doses to non-human biota. An assessment is presented in Eden and Barber</p>	<p>We agree that LLW Repository Ltd has 'an understanding' of background levels of radioactivity, but we have not yet seen a demonstration that this is adequate in all respects. In the Level 2 monitoring report it is noted that, as monitoring data are not available prior to 1958 to provide true background levels, monitoring data for the past two years are used to define the current baseline levels for the calculation of control and compliance levels. Although there is a substantial amount of available radionuclide activity concentration data in a wide range of environmental media, no attempt has been made to establish background concentrations in a similar way to that done for non-radioactive contaminants (Speed and Fretwell 2010), although it is noted that the contribution from Sellafield will mask the contribution from the LLWR (Thorne and Schneider 2011). Furthermore, we note that the non-human biota assessment of the current radiological impacts to the ecosystems local to the LLWR draws heavily from relatively old monitoring data cited by Eden and Barber (2007) and studies not primarily intended for the assessment of the impact of the LLWR (see IRF ESC-RO-ASO-001).</p> <p>We note that, although LLW Repository Ltd committed to comparison between levels of radioactivity arising from the facility and those present naturally as a supporting safety argument (see Baker et al. 2008), this was not carried through to the 2011 ESC. We</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
			(2007).	<p>recommend that further effort should be made to improve understanding of background levels of radioactivity in and around the site in the future ESC (Recommendation SUE51).</p> <p>BIO_004.2 – Issue closed - subsumed into IRFs ESC-RO-ASO-001, 002 and 003</p> <p>GRA Requirement R9 requires 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'.</p> <p>This should include consideration of impacts on non-human biota as well as more general effects such as damage to habitats. In the 2011 ESC, impacts to non-human biota are presented by Thorne and Schneider (2011). However, we identified some deficiencies in the comprehensiveness of this assessment, as documented in IRFs ESC-RO-ASO-001, 002 and 003. These issues were addressed to our satisfaction and have been closed, albeit with a number of recommendations for future improvements.</p>
BIO_005	Geosphere-biosphere interface	BIO_005.1 Evaluate the effect of further alternative geosphere-biosphere interfaces with respect to the most significant	BIO_005.1 – Accepted / included in the 2011 ESC All relevant geosphere-biosphere interfaces will be investigated for pathways and	<p>BIO_005.1 – Issue closed with recommendation</p> <p>The point of natural groundwater discharge is the intertidal region of the Drigg beach. The 2011 ESC assessment model considers</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>pathways and PEGs.</p> <p>BIO_005.2</p> <p>Demonstrate that there is mass conservation between the geosphere and biosphere models.</p>	<p>scenarios within the 2011 ESC. The emphasis will, however, be on possible interfaces in the period up to 5,000 years after present (AP). Beyond this time more generic stylised scenarios are appropriate.</p> <p>BIO_005.2 – Accepted</p> <p>Should be an automatic and necessary check within any model. However, cautious treatment of each pathway may imply some mass creation overall.</p>	<p>geosphere input to the local coastal waters and sediments; discharges to other model locations, for example the beach, are not considered. Due to the extent of dilution of groundwater in the marine environment, LLW Repository Ltd considers that the effect of this uncertainty is negligible (LLW Repository Ltd 2013). Discharges to the Drigg stream are also assessed, as are simple calculations for estuarine and lagoon release.</p> <p>In our appropriate assessment of protected habitats (Environment Agency 2014) we assess the long-term impact of contaminated groundwater discharges. We accept that radionuclide discharges to the beach or intertidal area are subject to considerable dispersion and dilution in the wider marine environment. However, as part of future ESC updates we recommend that LLW Repository Ltd further explores the effect of cliff recession on the geosphere-biosphere interface. This should take into account the uncertainty associated with projected groundwater flow pathways in terms of pathway length, spatial variability and location of discharge to the beach (Recommendation ASS6).</p> <p>BIO_005.2 – Issue closed</p> <p>Agreed, and we assume such checks will be made for all models. An advantage of using a GoldSim model is that it includes strict conservation of mass for chemical species (accounting for decay and ingrowth) and water.</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
BIO_006	Selection and characterisation of exposed groups	<p>BIO_006.1 Account explicitly for uncertainties in the properties and characteristics of transport pathways (for example using probabilistic techniques) in order to calculate the expectation values of dose and risk to PEGs for comparison with the design target.</p> <p>BIO_006.2 Calculate doses to PEGs exposed to individual pathways, to clarify the key routes for radionuclides to reach the accessible environment and give rise to doses.</p> <p>BIO_006.3 Justify the assumptions made concerning the fate of material excavated during human intrusion and subsequent land use, or provide dose calculations for a broader set of intrusion scenarios.</p> <p>BIO_006.4 Use the same assumptions on the habits and characteristics of PEGs in calculations of</p>	<p>BIO_006.1 – Not a biosphere issue, but accepted</p> <p>Not a biosphere issue. Probabilistic calculations will be carried out for selected cases in the 2011 ESC, see (Baker et al. 2008).</p> <p>BIO_006.2 – Accepted</p> <p>We agree it is necessary to understand both the route of migration to the biosphere and the modes of exposure. Such presentations will be included in the 2011 ESC.</p> <p>BIO_006.3 – Partly accepted but intrinsically problematic</p> <p>The assumptions regarding human intrusion in the 2002 PCSC are cautiously representative, that is they involve representative amounts of excavated waste and cap materials distributed on land that is used in such a way that doses are reasonably maximised. A broader set of intrusion cases will be addressed in the 2011 ESC, see section 5.9 of (Baker et al. 2008), but choice of assumptions must remain</p>	<p>BIO_006.1 – Issue closed with recommendation</p> <p>We agree that we would not expect probabilistic techniques to be applied to the detailed modelling of reference biospheres for long-term assessments. Consideration of uncertainty in selecting and substantiating parameter values for deterministic calculations is covered in Thorne (2009). However, there are places where it is not evident which data have been carried through to assessment calculations (for example, typical or high foodstuff consumption rates). It is recommended that PEG habits for each pathway, and associated uncertainties, are more clearly documented in future ESCs (Recommendation ASS7).</p> <p>BIO_006.2 – Issue closed with recommendation</p> <p>There is not always consistency in the way doses to PEGs between different pathways are modelled in the 2011 ESC documentation. For example, the groundwater pathway considers a composite set of behaviours including exposures resulting from both time spent on the beach/foreshore environment and consumption of marine foodstuffs. Doses from each individual exposure route are not documented. In contrast, the coastal erosion pathway PEGs assess occupancy exposures separately from ingestion of marine foodstuffs. This observation was taken forward in IRF ESC-TQ-ASO-003. Although this issue was addressed to our satisfaction and the</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>doses arising from both the groundwater and gas pathways.</p> <p>BIO_006.5</p> <p>Base its safety case on calculated risks to reasonable PEGs and not on arguments concerning inappropriate and undemonstrated conservatisms.</p>	<p>largely be matter of expert opinion and/or consensus with stakeholders, especially the EA.</p> <p>BIO_006.4 – Partly accepted / necessary work complete</p> <p>Definition of PEGs by Thorne (2007) means consistent PEG characteristics can be used where the PEG is 'the same'. On the other hand, different pathways may lead to exposure of different PEGs.</p> <p>BIO_006.5 – Accepted / necessary work complete</p> <p>Definition of PEGs has been reviewed and characteristics defined by Thorne (2007). This is based on generalised descriptions of observed behaviours in the region.</p>	<p>IRF closed, it is recommended that future ESC updates consider PEGs from different pathways in a consistent manner and that there is clarity with regard to the magnitude of doses arising from each individual exposure route (Recommendation ASS21).</p> <p>BIO_006.3 – Issue closed</p> <p>Agreed with reference to Hicks and Baldwin (2011).</p> <p>BIO_006.4 – Issue closed</p> <p>Agreed with reference to Thorne (2009).</p> <p>BIO_006.5 – Issue closed</p> <p>Agreed with reference to Thorne (2007).</p>
BIO_007	Selection and use of climate analogues	<p>BIO_007.1</p> <p>Provide a critical assessment of the issues relating to the up-scaling of short-term observations from individual meteorological stations to represent temporal and spatial variability within system states, and justify, using scoping calculations or sensitivity</p>	<p>BIO_007.1 – Partly accepted / work complete</p> <p>Consideration of climate analogues is given in Thorne and Kane (2007). The level of detail implied in this comment is disproportionate given the stylised nature of future biosphere assessment.</p>	<p>BIO_007.1 – Issue closed</p> <p>Given the reduced timescales considered in the 2011 ESC, we agree that the level of detail implied in the recommendation is no longer necessary.</p> <p>BIO_007.2 – Issue not relevant</p> <p>This recommendation is not relevant to the 2011 ESC.</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>studies, the assumptions made in the 2002 PCRSA calculations.</p> <p>BIO_007.2</p> <p>Justify why the full range of climate analogue sites identified has not been used as the basis for deriving patterns of land-use change and human activities at Drigg.</p>	<p>BIO_007.2 – No longer relevant</p> <p>See above. Focus of assessment on timescale up to 5,000 years reduces the relevance of such detail.</p>	
BIO_008	Treatment of current climate conditions	<p>BIO_008.1</p> <p>Undertake sensitivity analyses to determine whether variability in climatic conditions could have a significant effect on derived parameters such as cap infiltration.</p>	<p>BIO_008.1 – Accepted / work complete</p> <p>Variability in climatic conditions has been considered in calculation of cap infiltration and erosion (Thorne 2008b).</p>	<p>BIO_008.1 – Issue carried through to ESC-FI-027</p> <p>LLW Repository Ltd investigated long-term cap infiltration and erosion in Thorne (2008b). This information was used to support the elicitation of cap erosion rates, which take into account changing climate (Jackson et al. 2011). The company assumes an increase in HER of 13% to account for climate warming (Hartley et al. 2011). Substantiation for the increase of 13% is provided by Thorne (2010). Infiltration is assumed to be controlled by the performance of the cap hydraulic conductivity.</p> <p>We consider the approach to the elicitation of future cap filtration ranges to be appropriate. We would like to see greater utilisation of the long-term cap performance information presented in Thorne (2008b) and have asked LLW Repository Ltd to further investigate the long-term cap performance, evolution and failure of the cap in FI ESC-FI-027.</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				The use and substantiation of HER values in the 2011 ESC is discussed in PAR-005.1.
BIO_009	Non-human receptors	BIO_009.1 Calculate doses to non-human biota for the entire assessment period using the same environmental concentrations for radionuclides as used for the calculation of doses to humans.	BIO_009.1 – Accepted / work complete An assessment of impacts to non-human biota, including doses at times of peak concentrations in a 4,000 year and 50,000 year time frame is presented in Eden and Barber (2007).	BIO_009.1 – Issue closed An updated assessment of impacts to non-human biota was presented in the 2011 ESC (Thorne and Schneider 2011). The environmental concentrations used in the calculations were taken from the assessment model used to calculated doses to humans (maximum concentrations during the assessment period).
BIO_010	Use of dose - risk conversion factor	No recommendation. The Review Group considers BNFL used the International Commission on Radiological Protection (ICRP) recommended dose-risk conversion factor appropriately.	No recommendation.	BIO_010 - Issue closed
BIO_011	Treatment of environmental change	BIO_011.1 Provide a more detailed assessment of the relative likelihood of different site evolutions. BIO_011.2 Provide a more thorough uncertainty analysis for the treatment of environmental change, including the duration of system states, sea-level and	BIO_011.1 – Not needed / underpinning work complete Climatic and landscape scenarios that bound future evolutions have been developed in Thorne and Kane (2007). Likelihood cannot be reliably assessed and the likely alternative evolutions lead to broadly similar conditions for radiological assessment. BIO_011.2 – No longer	BIO_011.1 – Issue closed We agree that a 'detailed assessment' of probabilities is unrealistic, and that probabilities cannot be reliably assessed. A discussion of different erosion scenarios (mechanisms and directions of erosion) is provided in Fish et al. (2010). BIO_011.2 and BIO_011.3 – Issues closed The assessment of emergent land is not directly considered in the 2011 ESC. However, we asked LLW Repository Ltd to assess a very

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
		<p>changes in emergent land and the location of the GBI, and the behaviour of radionuclides in evolving and non-evolving compartments.</p> <p>BIO_011.3 Assess the implications of using time-steps of up to 47,000 years to model an evolving biosphere and the use of initial rather than representative conditions to characterise system states.</p> <p>BIO_011.4 Augment the extrapolation of historical coastal erosion rates with appropriate erosion calculations, and relate estimates of erosion to assumed patterns of sea-level change.</p> <p>BIO_011.5 Assess its commitment to consider coastal defence measures in relation to the Shoreline Management Plan's conclusion that defences along the Drigg coast would restrict sediment supply to a significant section of coast.</p>	<p>relevant</p> <p>Emergent land scenarios are no longer considered as realistic, and will be considered only as a 'what-if' case.</p> <p>BIO_011.3 – No longer relevant</p> <p>No longer relevant.</p> <p>BIO_011.4 – Accepted / work complete</p> <p>Studies of coastal dynamics have been carried out (Halcrow 2008) and estimates of long-term erosion made based on these studies plus possible climate and sea-level change (Thorne and Kane 2007).</p> <p>BIO_011.5 – No longer relevant</p> <p>LLW Repository Ltd no longer considers sea defences an appropriate or viable option to protect the site in the long-term.</p>	<p>long-term scenario for the unlikely situation in which the LLWR is not disrupted by coastal erosion in IRF ESC-RI-ASO-006. The scenario assumed that the shoreline adjacent to the LLWR would become exposed as a result of the reversal of current sea level rise trends. This assessment was carried out on a 'what if' basis and has a very low probability of occurrence (LLW Repository Ltd 2012).</p> <p>We consider that LLW Repository Ltd has carried out an appropriate assessment of the potential consequences of the emergence of land associated with sea level fall.</p> <p>BIO_011.4 – Issue closed</p> <p>Coastal erosion rates in the 2011 ESC are derived from a combination of an empirical cliff line recession model, a process-based cliff recession model and an estuary evolution model (Fish et al. 2010). These models, together with expert judgement, have been used to inform coastal erosion rate estimates.</p> <p>BIO_011.5 - Issue closed</p> <p>Agreed, subject to adequate monitoring of coastal evolution being maintained, understanding being kept up to date and the ESC remaining consistent with best understanding.</p> <p>We note that we have asked LLW Repository Ltd to identify any significant changes to sea defences on the coastline to the north and south of Drigg and assess the implications in future</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				updates of the ESC. This should include changes to the current Shoreline Management Plan that could impact on the LLWR (see Recommendation SUE46 of Environment Agency 2015a).
BIO_012	Derivation of biosphere sorption database	<p>BIO_012.1</p> <p>Document the primary data sources (that is, the actual measurements) used to derive Kd values for biosphere modelling, document the expert judgement applied in evaluating the suitability of the data, and document the methodology used to derive the Kd database for the biosphere.</p> <p>BIO_012.2</p> <p>Assess the variability and uncertainty associated with biosphere Kds, and use these rather than arbitrary 'two orders of magnitude' ranges in sensitivity studies.</p>	<p>BIO_012.1 – Rejected</p> <p>The biosphere Kd values come from international tabulations and sources that have been recommended for use in biosphere studies, for example BIOMASS, and have been extensively reviewed. Further detailed review is not needed and would be disproportionate.</p> <p>BIO_012.2 – Rejected</p> <p>We consider it is appropriate to use orders of magnitude ranges in sensitivity studies where the aim is to test the importance of a parameter. If a risk or dose via a pathway was found to be crucially dependent on a Kd value, then greater effort would be focused on the particular radionuclide and soil/sediment/waste form conditions and case-specific justification may be derived.</p>	<p>BIO_012.1 – Issue closed with recommendation</p> <p>Biosphere Kd data are taken from the review by Thorne (2008a). Our review of the 2008 Schedule 9 Requirement 2 submission (Environment Agency 2010) noted that Thorne (2008a) provides a thorough, coherent and largely well reasoned review of the data. We noted that in places it was difficult to ascertain what data had been taken through to the assessment models. However, for Kds, this has been addressed in the 2011 ESC by Table E6 of Kelly et al. (2011).</p> <p>We still consider that there is a lack of data that reflect local conditions, which could provide a useful context, particularly in cases where generic ranges of parameter values are very large because of the way in which behaviour varies with different conditions, and we recommend that site-derived Kd data should be used whenever possible (Recommendation SUE54).</p> <p>See also our response on BIO_001.1 and Environment Agency (2015a).</p> <p>BIO_012.2 – Issue closed with recommendation</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				<p>The 2011 ESC acknowledges that there are significant uncertainties in many processes, including sorption. The partitioning of radionuclides between solid (sediment) and aqueous media in assessment modelling is subject to high uncertainty (LLW Repository Ltd, 2013). However, contrary to the entry in the FEP and uncertainty tracking system (LLW Repository Ltd 2013), the effect of variability and uncertainty in biosphere sorption coefficients is not considered in the safety assessment (although uncertainty in near-field and geosphere sorption is). It is recommended that the forward programme looks in more detail at this potentially significant uncertainty (Recommendation ASS8).</p>
BIO_013	Collective radiological impact	<p>BIO_013.1 Extend the calculations of collective dose to include release of radionuclides to the accessible environment after 4,000 years post-closure.</p> <p>BIO_013.2 Present the results of its collective dose calculations in a series of 100-year periods from closure so as to demonstrate that the calculations pass the time of maximum collective dose.</p>	<p>BIO_013.1 – Rejected The ICRP advises that doses into the future should not be considered as measures of health detriment (ICRP 2000) and hence collective dose is not a useful measure in the long-term.</p> <p>We do not propose to present estimates of collective dose for the period after authorisation in the 2011 ESC.</p> <p>BIO_013.2 – Rejected See above.</p>	<p>BIO_013.1 and BIO_013.2 – Issues closed</p> <p>The 2011 ESC lacks an assessment of collective dose to members of the public. We acknowledge that collective dose to members of the public is not typically required to be assessed in repository safety assessments. However, the LLWR presents a special case because of the issue of coastal erosion, which may take place on a timescale commencing as early as a few hundred years after closure. We consider that information on collective doses is potentially significant for our regulatory decision-making in this case and will assist us in communicating the results of the ESC.</p> <p>We asked LLW Repository Ltd to carry out an assessment of collective doses per year of</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to the recommendations	EA comment on LLW Repository Ltd's position
				LLWR operation for the UK, Europe and the World, expressed on an average per caput basis, integrated up to 500 years from now. Because of the predicted erosion of the LLWR over a timescale of several 100s to several 1000 years, we did not expect the collective dose calculations to extend 4000 years post-closure. The assessment, presented in Soetens and Jackson (2013), met our expectations (see Environment Agency 2015c) and demonstrated that collective doses would be negligible.

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12. Appendix 7. GAS IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
GAS_001	Supply of information on gas generation and transport	<p>GAS_001.1 Consider taking a probabilistic approach to addressing uncertainty in gas-related issues to provide a clearer indication of the likelihood of the situations that result in high calculated risk occurring (for example short Rn-222 diffusion path).</p> <p>GAS_001.2 Provide information linking the screened-in gas-related FEPs to modelled parameters on the Parameter Input Forms, and provide information on the relationship between the terms in the DEGAS mathematical equations and parameters and the gas-related FEPs.</p>	<p>GAS_001.1 – Accepted / to be addressed in the 2011 ESC</p> <p>We will be considering a probabilistic approach to addressing uncertainty in the gas pathway, for both C-14 and radon, but note that a probabilistic approach is only warranted if justified pdfs can be defined for the key parameters.</p> <p>GAS_001.2 – No longer relevant</p> <p>A simplified approach to FEP management is proposed for the 2011 ESC, see section 5.3.3 of the 'Approach to 2011 ESC' (Baker et al. 2008).</p>	<p>GAS_001.1 – Issue closed</p> <p>The 2011 ESC gas pathway assessment focused on two main radionuclides in the post-closure stage of the facility; C-14 and Rn-222. LLW Repository Ltd has, through Small et al. (2011), looked at a number of variant cases that will affect the C-14 distribution into the gas phase. LLW Repository Ltd has subsequently taken the results from these variants and fed them into the assessment calculations to determine the potential risk to PEGs (LLW Repository Ltd 2011a).</p> <p>LLW Repository Ltd also assessed deterministic scenarios for Rn-222 for intrusion into the waste and for migration of gas through the cap using a number of variant cases involving alternative profiling of the cap (LLW Repository Ltd 2011a).</p> <p>These models and scenarios provided confidence that a suitable range of deterministic potential variants were assessed to adequately address uncertainty in the baseline scenario without use of probabilistic models.</p> <p>GAS_001.2 – Issue closed</p> <p>LLW Repository Ltd took a simplified approach to dealing with uncertainty associated with the gas pathway, as detailed in the FEP and uncertainty tracking system (LLW Repository Ltd 2013). Uncertainty is associated with two gas</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
				<p>pathway models; one for C-14 and the other for Rn-222. The uncertainty in each of these areas can be linked back to the models and LLW Repository Ltd has assessed what the likely effects would be on the ESC.</p> <p>Although this IAF is not totally relevant to the present case, the information presented within the 2011 ESC has addressed our concerns in this area.</p>
GAS_002	Treatment of gas generation processes	<p>GAS_002.1 Explain why the gas vent model is appropriate for assessment of the gas pathway in the long-term when degradation of the vent system might occur.</p> <p>GAS_002.2 Evaluate the possible contribution of aluminium and copper corrosion to gas generation and justify the values of mass fraction of metals as plates and as spheres in the different disposal regions, the values of metal plate thickness, and the values of metallic sphere radii.</p> <p>GAS_002.3 Assess the sensitivity of PCRSA results to uncertainty</p>	<p>GAS_002.1 – Accepted / work in hand</p> <p>Work is in hand to consider the migration of gases in the waste and profiling and release through the cap.</p> <p>GAS_002.2 – Accepted / work in hand</p> <p>The contribution of aluminium and copper to gas generation is considered to be insignificant compared to gas generation from steel. However, as part of our review and update to DRINK, we will consider this bias further. The geometry of disposed metal items is likely to remain an issue for judgment, although this is another area where we will consider sensitivities to the assumptions made.</p>	<p>GAS_002.1 – Issue closed with recommendation</p> <p>LLW Repository Ltd carried out work using a gas model to understand the effect of the vent on the gas pathway (LLW Repository Ltd 2011a). This included assessment of the effect of varying parameters associated with the vent on the transfer of C-14 and Rn-222 gas through the cap and the effect the vent will have on the transport of the gas.</p> <p>We are satisfied that this work addresses our predominant concerns raised on the 2002 PCSC. However, we note that no final decision has been made on the design of the vent or how long the vent will be left open. These decisions will have implications on the transport of gases from the LLWR. We recommend that LLW Repository Ltd assesses any engineering changes to the vent on the gas transport properties and the consequent effect on the assessment calculations. LLW Repository Ltd should ensure that any subsequent changes are assessed in future iterations of the ESC</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		associated with variations in cellulose degradation rates.	GAS_002.3 – Accepted / to be included in the 2011 ESC Accepted, see also GAS_001.1.	<p>(Recommendation ASS20). The assessment should inform the forthcoming gas management strategy (see FI ESC-FI-024).</p> <p>GAS_002.2 – Issue closed</p> <p>As part of the 2011 ESC, LLW Repository Ltd carried out an exercise assessing the corrosion rates of copper and aluminium.</p> <p>The corrosion rate of aluminium is thought to be insignificant and the generation of gas from aluminium will be significantly less than that from the steel present within the inventory (Jackson et al. 2011).</p> <p>Copper is thought to be thermodynamically stable under anoxic conditions and its corrosion will be lower than that of mild steel present in the disposals (Jackson et al. 2011).</p> <p>We note that the inventories of both aluminium and copper are lower than that of steel, and that the latter will undergo preferential corrosion (LLW Repository Ltd 2011b). In addition, we note that the total quantity of hydrogen that will be produced is unlikely to result in a safety concern as the gas is not retained within the facility, and also because hydrogen is used by microbes for energy conversion mechanisms. Thus we consider that the generation of hydrogen from aluminium and copper will not be a significant issue at the LLWR.</p> <p>GAS_002.3 – Issue closed</p> <p>LLW Repository Ltd demonstrated the effect of differing cellulose degradation rates in the 2011</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
				ESC using the GRM (Small et al. 2011). Cellulose is primarily associated with gas production during the period of authorisation. In 2002, C-14 was primarily thought to be associated with the cellulose fraction of the waste. However, according to the 2011 ESC, the main contributor is now thought to be ferrous metals, which will degrade at a substantially slower rate. As part of the GRM study, LLW Repository Ltd looked at variant cases of slower degradation rates of 0.3 and 0.1 to understand the effects on the release of C-14. We thus consider this issue closed.
GAS_003	Treatment of radionuclides in the gas phase	<p>GAS_003.1 Provide a cross-reference to information that supports the screening-out of methylated Se-79, Sn-126 and Pb-210 on the basis of their low probability of occurrence.</p> <p>GAS_003.2 Provide an explanation of what the emanation factor represents and justify its value.</p> <p>GAS_003.3 Clarify the results of the calculations on gas release fractions in order to confirm a release fraction of 10% C-14.</p> <p>GAS_003.4</p>	<p>GAS_003.1 – Minor see opposite</p> <p>Minor. There are several possible references, for example see Rodwell et al. 2003.</p> <p>GAS_003.2 – Minor see opposite</p> <p>Minor. The factor comes from Appendix B in UNSCEAR 2000.</p> <p>GAS_003.3 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>The association of C-14 bearing waste with organic degradable waste has been scoped (Ball et al. 2007).</p>	<p>GAS_003.1 – Issue closed Rodwell et al. (2003) is not cited in the 2011 ESC, but this issue is not thought to be of great significance. We consider that the radionuclide inventory developed and used in the 2011 ESC was sufficiently comprehensive and representative (Environment Agency 2015).</p> <p>GAS_003.2 – Issue closed</p> <p>GAS_003.3 and GAS_003.4 – Issue closed LLW Repository Ltd modelled a number of variant cases to assess the effects of a number of parameters on the release of C-14 to the gas pathway (Small et al. 2011). Results were fed into the radiological assessment calculations for the gas pathway. The values fed into the assessment calculations cover the range of potential releases of gas from the near field.</p> <p>As part of the assessment for C-14, LLW</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>Provide information to support the assumption that the mass of cellulosic waste will decay as an exponential function of time.</p> <p>GAS_003.5</p> <p>Provide more information about the derivation of the DEGAS atmospheric dispersion model and the selection of atmospheric stability categories.</p> <p>GAS_003.6</p> <p>Provide guidance as to when inhalation dose factors need to be augmented to allow for external irradiation and absorption through intact skin.</p> <p>GAS_003.7</p> <p>Provide information on the potential for tritium to contaminate foodstuffs and contribute to doses by ingestion.</p> <p>GAS_003.8</p> <p>Provide an explanation as to why one of the six evaluation points for the gas pathway is a home located on the northern wall of vault 8, rather than any</p>	<p>Further work is planned before the 2011 ESC</p> <p>GAS_003.4 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>The assumption is the simplest option based on linear rate process. It also yields the highest rate of gas generation at early times and is thus cautious.</p> <p>GAS_003.5 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>This is not relevant to the post-closure assessment; other exposure pathways dominate. Assessment of gaseous releases prior closure will be considered in the 2011 ESC.</p> <p>GAS_003.6 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>External irradiation is not relevant to the key radionuclides H-3, C-14, Rn-222. Absorption through intact skin is minor and effectively included in the ICRP dose per unit inhalation factors for H-3 and C-14.</p>	<p>Repository Ltd assessed the effect of differing rates of degradation of cellulose on gas production. We note that the assumption that the decay process of cellulose is liable to result in the highest rate of gas being produced is cautious. We thus consider these issues closed.</p> <p>GAS_003.5 – Issue not relevant</p> <p>The DEGAS model is not used in the 2011 ESC and thus this IRF is no longer relevant. The effect of atmospheric dispersion during the period of authorisation has been considered using a simple Gaussian plume model.</p> <p>GAS_003.6 – Issue closed</p> <p>We note that the greatest risk posed by the radionuclides listed in Table 3 of Thorne et al (2011) is from tritium. The other species present within the plume are liable to only present a risk from operational aspects. We note that, for low activity releases such as C-14, the main route by which PEGs will be at risk is through the accumulation of activity in the environment, and that the direct radiological impacts from the plume are minor.</p> <p>Other particulates containing gamma activity may result in doses to the skin, but transfer through the skin of radionuclides from the plume, is low (National Dose Assessment Working Group (NDAWG) 2009). We also note that inhalation from re-suspended dust is also classified as low. The data presented within the 2011 ESC address our concerns with regard to</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>other location on the cap, and clarify why gases from all parts of the disposal site are assumed to be released to the dwelling on the cap.</p> <p>GAS_003.9</p> <p>Consider the likelihood of a dwelling existing on a 3 m thick cap after 250 years, and undertake analyses aimed at improving confidence in the cap evolution after closure and reducing uncertainty in cap thickness. This analysis should include a discussion as to why significant cracking would not occur in the cap, and in general why advection is not significant.</p>	<p>GAS_003.7 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>Airborne tritium gas is of no importance. Tritiated water will be diluted in water vapour. The airborne releases are in any case very small.</p> <p>GAS_003.8 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>We will revisit the gaseous exposure assumptions for the 2011 ESC in line with the defined PEGs (Thorne 2007).</p> <p>GAS_003.9 – Detailed / Can be answered or will be dealt with in the 2011 ESC</p> <p>We will revisit the gaseous migration assumptions for the 2011 ESC. Work is in hand to consider the migration of gases in the waste and profiling and release through the cap.</p>	<p>this issue.</p> <p>GAS_003.7 – Issue closed</p> <p>Potential doses due to the uptake of tritium in foodstuffs from gaseous releases are assessed in the 2011 ESC (Penfold and Paulley 2011).</p> <p>GAS_003.8 – Issue closed</p> <p>LLW Repository Ltd assesses different evaluation points for the gas pathway in the 2011 ESC to those used in the 2002 PCSC (LLW Repository Ltd, 2011a; Limer and Thorne 2011).</p> <p>During the period of authorisation, radiological impacts are assessed to occupants of a dwelling located on the edges of the site. For the post-closure period, impacts are assessed to occupants of a dwelling located at a number of different locations on the site cap. Thus the 2011 ESC assessment covers a greater range of scenarios for a dwelling on the cap compared with the 2002 PCSC and this issue is considered to have been treated satisfactorily.</p> <p>GAS_003.9 – Issue closed subsumed into IRF ESC-TQ-INF-035</p> <p>This issue is of greatest relevance to Rn-222 transfer through the cap. The condition of the cap will be important in determining how well Rn-222 is held up within the cap and thus the number of half lives that Rn-222 will decay by during the time taken to migrate through the cap. The potential for cracking of the cap and subsequent effects on Rn-222 migration and</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
				dose to a dweller located on the surface of the cap have been raised in IRF ESC-TQ-INF-035, which has been satisfactorily addressed. The effect of the cap on dose from C-14 is minimal due its longer half life.

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13. Appendix 8. DIS IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
DIS_001	FEP screening - future human actions and disruptive events	<p>DIS_001.1 Assemble and screen a single list of EFEPs, including the range of possible site development activities, and compare its EFEP list with FEP lists derived for other LLW disposal facilities.</p> <p>DIS_001.2 Improve the traceability of FEP screening arguments by providing sufficient information within the catalogue of FEP screening decisions for an independent reviewer to evaluate the basis for BNFL's decisions, including provision of adequate and specific references to supporting literature. BNFL should include adequate documentation for the elimination of FEPs from PCRSA calculations on the basis of well-defined screening criteria (screened-out FEPs), and adequate/traceable documentation of the treatment in the PCRSA of FEPs accounted for in the</p>	<p>DIS_001.1 and DIS_001.2 – Accepted / underpinning work complete / to be addressed in the 2011 ESC</p> <p>A formal expert elicitation study has identified possible developments and events at the site taking account of patterns of land use on the West Cumbrian Coastal Plain (Thorne 1996). This was followed by a report (Halcrow 1998) that considered how each of the common site uses would be implemented if the presence of a repository at the LLWR site were to be forgotten.</p> <p>We are revisiting these studies and will include a list of human activities and events that could affect the site in the 2011 ESC, and set out screening arguments for those that are not taken forward. Thus, a more balanced discussion and presentation will be developed of the uncertainties around the impacts of possible human</p>	<p>DIS_001.1 and 001.2 - Issues closed</p> <p>A FEP and uncertainty tracking system was developed for the 2011 ESC (Lean and Willans 2010), which included a simplified FEP list. However, a copy of the supporting database was not received until early 2013 (LLW Repository Ltd 2013a).</p> <p>The term 'EFEPs' (external FEPs) is not used in the 2011 ESC. Instead, FEPs are classified according to exposure pathway. Coastal erosion is the only disruptive event considered, which we consider appropriate given the expected relatively short timeframe up until disruption of the site by coastal erosion.</p> <p>See our response on COR_015 with regard to treatment of FEPs and associated uncertainty.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		calculations (screened-in FEPs).	actions at the site.	
DIS_002	Human intrusion assessment	<p>DIS_002.1</p> <p>Undertake further work on risk management in view of the relatively high calculated doses and risks from human intrusion. BNFL should undertake a study to identify and document a thorough list of options that could reduce the likelihood and/or consequences of human intrusion into the trenches. BNFL should consider the benefits and detriments of each of the identified options at the appropriate level of detail, including their environmental impacts, technical viability, public and worker health and safety, and social, political and cost implications.</p> <p>DIS_002.2</p> <p>Link necessary work on risk management to further work on human intrusion assessment to respond to the comments raised in this IAF - on code verification, site development and occupation</p>	<p>DIS_002.1 – Accepted / work complete</p> <p>Extensive work has been undertaken on risk management options and has guided our current proposals for the site development (Baker et al. 2008a).</p> <p>DIS_002.2 – Largely superseded</p> <p>Detailed comments, largely superseded.</p> <p>In particular the proposed thicker cap reduces likelihood of intrusion into, or excavation of, the waste at times up to 5000 years, which is now the main period of interest.</p> <p>Our proposed approach to assessing human intrusion is set out in section 5.10 of Baker et al. 2008a.</p>	<p>DIS_002.1 – Issue closed - subsumed into IRFs ESC-RI-ASO-011 and ESC-RI-ASO-013</p> <p>LLW Repository Ltd conducted a major new human intrusion assessment in the 2011 ESC. We consider that this issue has largely been closed, although it has partly been superseded by IRF ESC-RI-ASO-011 (with respect to heterogeneity of waste and assessment of illicit material recovery) and IRF ESC-RI-ASO-013 (with respect to exposure to radioactive sources). The actions in these IRFs have subsequently been adequately addressed and have been closed.</p> <p>Also see our response to COR_003.</p> <p>DIS_002.2 – Issue closed</p> <p>LLW Repository Ltd conducted a major new human intrusion assessment in the 2011 ESC. We agree that the recommendation is largely specific to the 2002 assessment and no longer relevant in detail as different models and assumptions are used.</p> <p>Given the shorter timeframe considered in the 2011 ESC, we consider that the treatment of cap erosion with respect to human intrusion is appropriate.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>subsequent to cap erosion, the characteristics of a site occupier PEG, exposure likelihood, and risk assessment - to produce a more defensible consideration of the potential impacts associated with future human actions. In particular, BNFL should:</p> <p>Provide evidence that the implementation of the human intrusion model in AMBER is correct.</p> <p>Re-consider the likelihood of cap erosion, and the need for CPS calculations to consider a PEG that resides near the cap at times when the cap may have eroded and knowledge of the site lost.</p> <p>Re-consider the model implementation for an agricultural site occupier PEG, and the potential additive impact on doses of 'non-intrusive' pathways considered in the CPS, such as the possible use of locally derived contaminated groundwater.</p> <p>Re-evaluate its presentation of arguments on the likelihood of</p>		

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>various kinds of future human action.</p> <p>Consider the potential risks associated with future human actions, until such time as ICRP 81 is accepted as the basis for regulation in the UK.</p>		
DIS_003	Waste inhomogeneity	<p>DIS_003.1</p> <p>Link necessary work on risk management to further inspection of historical disposal records in an attempt to better define the nature and extent of any unusual disposals having particularly high concentrations of specific radionuclides in the trenches.</p> <p>DIS_003.2</p> <p>Undertake a study to identify and document a thorough list of options that could reduce the likelihood and/or consequences associated with exposures to unusual disposals having particularly high concentrations of specific radionuclides (for example, Th-232, Ra-226). This will entail consideration of the benefits and detriments of each of the options, including</p>	<p>DIS_003.1 – Accepted / underpinning work complete / will be addressed in the 2011 ESC</p> <p>The heterogeneity of disposals has now been mapped (Lennon et al. 2008), and this information will be used to estimate variability of doses from human intrusion scenarios related to the heterogeneity. We note, however, that most exposure scenarios lead to exposure to significant volumes of waste.</p> <p>DIS_003.2 – Accepted / detailed work in hand / will be addressed in the 2011 ESC</p> <p>General options have been considered (Edwards and Alexander 2005).</p> <p>Detailed work related to the impacts of selective retrieval of higher activity waste is in hand,</p>	<p>DIS_003.1 and DIS_003.2 – Issues carried through to ESC-FI-010 and ESC-FI-013</p> <p>Since 2002, LLW Repository Ltd has carried out a significant amount of work investigating heterogeneity of waste in the trenches. Despite this, we consider that exposure to higher activity wastes and particles were not adequately assessed in the 2011 ESC.</p> <p>This issue was raised in IRF ESC-RI-ASO-010 (with regard to heterogeneity in the coastal erosion assessment) and IRF ESC-RI-ASO-011 (with regard to heterogeneity in the human intrusion assessment). The actions in these IRFs have subsequently been adequately addressed and have been closed.</p> <p>LLW Repository Ltd has subsequently sought to optimise waste disposal operations to take account of the likelihood and/or consequences associated with the exposures to unusual disposals having particular high concentrations of specific radionuclides. The company has derived WAC to limit disposals of higher activity particles and discrete items (LLW Repository Ltd 2013b).</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		their environmental impacts, technical viability, public and worker health and safety, and social, political and cost implications.	see section 4.3 of the 'Approach to 2011 ESC' (Baker et al. 2008a).	We have asked LLW Repository Ltd to present information on the distribution of key radionuclides and key materials for disposals to the vaults in future versions of the ESC, where benefits of doing this are identified, in FI ESC-FI-010. We have also asked the company to consider historical disposals of discrete items, assess the possible implications and identify any resulting action required in advance of emplacement of the final cap in FI ESC-FI-013.
DIS_004	Site destruction scenarios	<p>DIS_004.1</p> <p>Conduct further work on risk management in view of the relatively high calculated conditional doses / risks from coastal erosion. BNFL should undertake a study to identify and document a thorough list of options that could reduce the likelihood and/or consequences of coastal erosion, and should consider each identified option at the appropriate level of detail. This will entail consideration of the benefits and detriments of each of the options, including their environmental impacts, technical viability, public and worker health and safety, and social, political and cost implications.</p>	<p>DIS_004.1 – Accepted / detailed work largely complete / with some additional work to be done before 2011 ESC</p> <p>A general consideration of risk management options is reported in Edwards and Alexander (2005). This has been extended by more detailed work on each of the most promising options as summarised in R2S9, Volume 2 (Baker et al. 2008b).</p> <p>Detailed work related to the impacts of selective retrieval of higher activity waste is in hand, see section 4.3 of the 'Approach to 2011 ESC' (Baker et al. 2008a).</p> <p>DIS_004.2 – Accepted / work complete</p>	<p>DIS_004.1 – Issue closed</p> <p>LLW Repository Ltd presents a comprehensive assessment of radiological impacts associated with coastal erosion in the 2011 ESC (LLW Repository Ltd 2011a; 2011b). We consider that LLW Repository Ltd has identified and implemented all reasonable measures and options that could reduce the consequences of coastal erosion with the assumption that no future intervention is required to deliver the measure.</p> <p>DIS_004.2 – Issue closed</p> <p>LLW Repository Ltd redefined the coastal erosion PEGs assessed in the 2011 ESC. The 2011 ESC builds on the latest climate change assessments and incorporates PEGs developed for the 'introduction' of waste into the coastal environment (Thorne 2007). The PEGs were developed with 'beach user' information derived from observations of the West Cumbria Coast. The PEGs were appropriately identified to take account of the nature of the eroding waste mass</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		DIS_004.2 Better justify assumptions underlying its consideration of potentially exposed groups for site termination events.	The work on definition of PEGs (Thorne 2007) provides the traceable basis to local and regional habit data. The use of this basis for assessment of PEGs most exposed during coastal erosion is set out in R2S9, Volume 5 (Sumerling 2008).	and the changes to beach stage resulting from the introduction of waste on to the beach.
DIS_005	Treatment of potentially disruptive, intermittent, natural events and processes	DIS_005.1 Undertake further work on risk management in view of the relatively high calculated doses and risks from non-human biotic intrusion. BNFL should undertake a study to identify and document a thorough list of options that could reduce the likelihood and/or consequences of non-human biotic intrusion into the trenches, and should consider each identified option at the appropriate level of detail. This will entail consideration of the benefits and detriments of each of the options, including their environmental impacts, technical viability, public and worker health and safety, and social, political and cost implications.	DIS_005.1 – Accepted / work complete The cap has been re-designed since 2002 (Belton 2007) and is designed to exclude intrusion by non-human biota. It is expected to be effective in this regard at least up to 5000 years, see (Thorne 2008). DIS_005.2 – No longer relevant The timescale for consideration of undisturbed performance is now reduced to ca. 5000 years, considering the site is likely be destroyed by coastal within this time period. The cap will prevent is expected to resist natural erosion and remain largely intact over the period up to at least 5000 years AP (Thorne	DIS_005.1 – Issue carried through to ESC-FI-027 Within our review of the 2011 ESC we highlight some areas where there is a lack of detailed performance assessment for functional elements of the repository engineering. Although adequate for this stage of development, we consider that the 2011 ESC would benefit from further work on substantiation that the bio-intrusion cobble layer in the closure engineered cap prevents bio-intrusion, provides drainage, reduces the likelihood of human intrusion and reduces erosion. We raised ESC-FI-027 to require further work in this area, addressing this IAF and similar issues identified during our 2011 ESC review. DIS_005.2 – Issue not relevant The large scale erosion and degradation of the engineered capping layer resulting in doses to animals and plants is not expected to occur prior to the disruption of the site by coastal erosion (Thorne 2008). With the exception of bio-

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>DIS_005.2</p> <p>Re-assess its calculations of doses to non-human biota in the light of the criticisms (see IAF DIS_002) that cap erosion has not been properly accounted for in 'undisturbed performance', by considering in more detail the possible doses to animals and plants that are active around the site as the cap degrades and erodes (see also BIO_009.1).</p>	2008).	<p>intrusion mechanisms described in DIS_005.1, we do not consider it necessary that the undisturbed performance of an eroding repository is assessed. We note that the 2011 ESC includes a separate assessment of doses to animals and plants during the disruption and coastal erosion of the site.</p> <p>Given the much shorter timescales before disruption of the LLWR are assumed in the 2011 ESC compared with the 2002 PCSC and the assessment of non-human biota impacts during the disruption of the site by coastal erosion, we consider this recommendation no longer relevant.</p>
DIS_006	Treatment of uncertainty - future human actions and disruptive events	<p>DIS_006.1</p> <p>Undertake further work on risk management in view of the relatively high and uncertain calculated doses and risks from human intrusion. BNFL should undertake a study to identify and document a thorough list of options that could reduce uncertainty associated with human intrusion calculations, the likelihood of human intrusion, and/or the consequences of human intrusion, particularly into the trenches. BNFL should consider the benefits and detriments of each of the</p>	<p>DIS_006.1 – Accepted / work largely complete</p> <p>A general consideration of risk management options is reported in Edwards and Alexander (2005). This has been extended by more detailed work on each of the most promising options as summarised in R2S9, Volume 2 (Baker et al. 2008b).</p> <p>Detailed work related to the impacts of selective retrieval of higher activity waste is in hand, see section 4.3 of the 'Approach to 2011 ESC' (Baker et al. 2008a).</p>	<p>DIS_006.1 – Issue closed - subsumed into IRFs ESC-RI-ASO-011 and ESC-RI-ASO-013</p> <p>Overall, we consider that the process of optimisation in the 2011 ESC has been carried out to an acceptable standard. The 2011 ESC makes the case for the disposal facility to be closed without the need for selective retrieval of waste (Paulley and Egan 2011).</p> <p>We requested a more complete assessment of coastal erosion and human intrusion scenarios associated with exposure to higher activity wastes and particles in IRF ESC-RI-ASO-011 (with regard to the human intrusion assessment) and IRF ESC-RI-ASO-013 (with regard to low activity sources). The actions in these IRFs have subsequently been adequately addressed and have been closed.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		<p>identified options at the appropriate level of detail, including their environmental impacts, technical viability, public and worker health and safety, and social, political and cost implications.</p> <p>DIS_006.2</p> <p>Link necessary work on risk management to further work on human intrusion assessment to produce a more defensible consideration of the impact of uncertainties associated with future human actions. Key assessment assumptions and uncertainties associated with BNFL's calculated conditional doses include: dilution of waste in soil, amount of waste excavated, identification of PEGs and exposure pathways, and processes considered in the stylised human intrusion assessment calculations - in particular, the treatment of the radon emanation factor.</p> <p>DIS_006.3</p> <p>Re-consider the screening of resource exploration/exploitation and, if</p>	<p>DIS_006.2 – Accepted / basis in place / some further consideration in the 2011 ESC</p> <p>Characteristics of human intrusion scenarios will be revisited for the 2011 ESC, see section 5.10 of the 'Approach to 2011 ESC' (Baker et al. 2008a). Assumptions regarding human intrusion are always uncertain and scenarios can only be illustrative. We will present the scenarios we propose to assess to the EA before the 2011 ESC.</p> <p>An empirically-based approach has been adopted to estimate exposures from radon following intrusion (Sumerling 2008).</p> <p>DIS_006.3 – Accepted / basis in place / further consideration in the 2011 ESC</p> <p>Characteristics of human intrusion scenarios will be revisited for the 2011 ESC, see above.</p>	<p>Also see our response to COR_003.</p> <p>DIS_006.2 – Issue closed - subsumed into IRFs ESC-RI-ASO-011 and ESC-RI-ASO-013</p> <p>We concluded that the 2011 ESC coastal erosion and human intrusion assessments do not include a complete assessment of all potential exposures, in particular those associated with exposure to higher activity wastes and particles. We therefore requested additional calculations, in particular for 'what if' scenarios, in IRF ESC-RI-ASO-011 (with regard to the human intrusion assessment) and IRF ESC-RI-ASO-013 (with regard to low activity sources). The actions in these IRFs have subsequently been adequately addressed and have been closed.</p> <p>Also see our response to COR_003 which describes two FIs that seek further investigation into the nature of discrete items and past disposals.</p> <p>DIS 006.3 - Issue closed</p> <p>The 2011 ESC has appropriately characterised and assessed human intrusion scenarios (LLW Repository Ltd 2011b and Environment Agency 2015).</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
		necessary, evaluate the potential implications of resource exploration/exploitation occurring in the future on the Drigg site.		
DIS_007	Supply of information - future human actions and disruptive events	<p>DIS_007.1</p> <p>Improve presentation of the PCSC so that key lines of reasoning and evidence are readily traceable, apparent and internally consistent.</p>	<p>DIS_007.1 – Accepted / to be addressed in the 2011 ESC</p> <p>Our overall approach is set out in section 5.10 of the 'Approach to 2011 ESC' (Baker et al. 2008a). We accept the need for clear documentation of assumptions and their basis in this area.</p>	<p>DIS_007.1 – Issue closed</p> <p>We consider that the documentation provided in the 2011 ESC provides a significant improvement over the 2002 OESC and PCSC. Lines of reasoning for the coastal erosion and human intrusion scenarios are clear and consistent. We consider that this issue can be closed.</p> <p>Also see our response to COR_024.</p>

References to Appendix 8

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14. Appendix 9. COD IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
COD_001	Supply of information	No recommendation for actions by BNFL.	No recommendation.	Agreed
COD_002	Recording of modelling assumptions	No recommendations for actions by BNFL or the Agency.	No recommendation.	Agreed
COD_003	GRWOLF usage and verification	No recommendations for actions by BNFL or the Agency.	No recommendation.	Agreed
COD_004	GEO usage and verification	<p>COD_004.1 Compare GEO with the MASCOT transport model, using the example reported in the GRWOLF PUG for flow comparisons.</p> <p>COD_004.2 Verify the assumption that transverse dispersion can be represented by widening of legs with distance along major plume paths.</p> <p>COD_004.3 Demonstrate the functionality of GEO in combination with TIMEDEP for an evolving hydrogeological system.</p>	<p>COD_004.1 – No longer relevant This recommendation has been superseded, since GEO is no longer a tool that will be used.</p> <p>COD_004.2 – No longer relevant This is a detailed modelling issue that would be considered if necessary in future assessments.</p> <p>COD_004.3 – No longer relevant This recommendation has been superseded, since GEO is no longer a tool that will be used.</p>	<p>COD_004.1, COD_004.2 and COD_004.3 – Issues not relevant We agree that the recommendations are specific to the tools used in the 2002 PCSC and no longer directly relevant.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
COD_005	BIOS usage and verification	No recommendations for actions by BNFL or the Agency.	No recommendation.	Agreed
COD_006	DEGAS usage and verification	No recommendations for actions by BNFL or the Agency.	No recommendation.	Agreed
COD_007	GRM usage and verification	COD_007.1 Include QA forms for test cases in all PVRs.	COD_007.1 – In hand or planned for the 2011 ESC We agree that QA needs to be appropriately recorded.	<p>COD_007.1 - Issue closed with recommendation</p> <p>The specific recommendation is not relevant to the use of GRM in the 2011 ESC. However, the general principle applies in that all models should be adequately tested and the testing fully documented.</p> <p>The documentation of code interlinkage and quality assurance is not presented as well in the 2011 ESC as it was in the 2002 PCSC. We queried this in IRF ESC-RO-ASO-007. In response, Shevelan (2013) signposted sources of evidence for an extensive programme of validation and verification of GRM including use of test cases. This includes blind validation tests against TVO experiments performed in Finland relating to C-14 gas for a fully saturated system. The model follows the experiments well and thus is validated for a saturated system. We consider that this satisfactorily addressed our query and we closed the IRF. However, we recommend that LLW Repository Ltd considers further work to support future GRM (or other near field code) modelling in relation to the partitioning of C-14 and the behaviour of C-14 in unsaturated vault</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to the recommendations	EA comments on LLW Repository Ltd's position
				<p>conditions (Recommendation INF22).</p> <p>We audited the use of GRM to support the groundwater pathway calculations in June 2013 (Fairhurst, 2013). The contractor, NNL, is accredited to ISO9001 and undertook the work in accordance with the company's quality manual. Areas of good practice were identified, for example, NNL described how it compared the outputs from GRM simulations to collected trench monitoring data and performed mass-balances of cement and cellulose leaching.</p> <p>We conclude that the GRM model used in the 2011 ESC was developed and used within a comprehensive and robust quality system covering both LLW Repository Ltd and its contractors.</p>

References to Appendix 9

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15. Appendix 10. PAR IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
PAR_001	Uranium solubility and the timing of key changes in near-field chemistry	PAR_001.1 Present an analysis of the significance of calcium uranate control on solubility in the vaults that excludes the influence of the trenches.	PAR_001.1 – Accepted / work complete We have undertaken a review, reported in Fowler et al. (2004), which addresses among other issues the likely solubility controls for uranium at the LLWR and addresses the issue raised in the recommendation.	PAR_001.1 – Issue closed - subsumed into IRF ESC-TQ-INF-026 Our review of this section of Fowler et al. (2004) concluded that: 'More detailed support would be required before adopting a changed representation in the models.' This does not suggest that the issue is fully resolved. We queried the narrow representation of uncertainty in uranium sorption and solubility for a reducing cementitious system, in particular the potential presence of mobility enhancing species, the full range of plausible environmental conditions within the disposal system and uncertainty in understanding of site monitoring data in IRF ESC-TQ-INF-026. In response, LLW Repository assessed a combined variant case that addressed this specific issue, allowing us to close the IRF.
PAR_002	Key sorption parameters	PAR_002.1 (geosphere sorption) Building on recommendation GEO_016.1, obtain better sorption parameters for uranium in the geosphere by: (i) Undertaking migration experiments (column and/or diffusion experiments) because these have the	PAR_002.1 – Rejected / not needed Geosphere sorption is not a major control on the maximum calculated impacts (from the water abstraction well) and therefore we do not regard it as a priority for further work. We have undertaken further sorption experiments on	PAR_002.1 – Issue closed The significance of uranium and its daughter radionuclides as contributors to groundwater pathway risk in the long-term is diminished in the 2011 ESC compared with the 2002 PCSC. We consider that the treatment of uranium sorption in the geosphere is fit for purpose. However, we have raised a recommendation under IAF GEO_016.2 for further analysis of geosphere sorption for radionuclides that dominate risk via

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>advantage that they more nearly simulate in situ conditions, although they do introduce new experimental difficulties.</p> <p>(ii) Developing improved speciation and surface complexation models together with good site characterisation data, which might provide more credible sorption values than geometric means of greatly differing batch sorption results. Such an approach could provide sorption values that reflect changes in pH and carbonate contents of the aqueous phase as the migration plume develops.</p> <p>(The Parameters Review Group made no recommendations regarding the near-field and biosphere Kds beyond those presented at NRF_013.1, NRF_013.4 and BIO_012.)</p>	<p>uranium sorption in the geosphere. There are pros and cons of undertaking column and diffusion experiments versus batch experiments. If detailed study was considered appropriate, then it is likely that both techniques would be used. However, we do not consider this to be proportionate because of the limited influence of geosphere sorption in the current assessment.</p> <p>We suggest that similar arguments are appropriate in relation to the use of better chemical models of speciation and surface complexation.</p>	<p>the groundwater pathway.</p>
PAR_003	Treatment of dilution and dispersion in the geosphere	<p>PAR_003.1</p> <p>Provide details and justification of the process by which the topology of the regional groundwater flow pathways was determined from the</p>	<p>PAR_003.1 / 2 / 3 – No longer relevant</p> <p>These are detailed technical comments relevant to the approach used in the 2002 PCSC. As the approach is now</p>	<p>PAR_003.1 – Issue not relevant</p> <p>Agreed</p> <p>PAR_003.2 – Issue closed</p> <p>LLW Repository Ltd developed a detailed 3D groundwater flow model for the 2011 ESC using</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>MODFLOW particle track results, and clarify why a thickness of 15 m has been chosen for the flow paths through the sandstone under colder climate conditions.</p> <p>PAR_003.2</p> <p>Undertake a detailed analysis of radionuclide migration from the Drigg disposal facility using appropriate groundwater flow and radionuclide transport models in order to demonstrate that the one-dimensional PCSC model provides an appropriate approximation of radionuclide transport in the geosphere. (See also recommendation GEO_010.1.)</p> <p>PAR_003.3</p> <p>Demonstrate that, for a Peclet number of 10, the effects of the variability in dispersivity over the network on the results of the risk assessment are insignificant, especially for radionuclides such as Sr-90 which are sensitive to dispersion, and verify that numerical dispersion is insignificant if the Peclet</p>	<p>different, we consider that these comments are no longer relevant.</p>	<p>ConnectFlow and calibrated using site data (Hartley et al. 2011). A simplified representation of the system, a GoldSim compartmental flow model, was also developed, which is embedded into the GoldSim assessment model for calculation of contaminant fate and transport. The 2010 Compartment Flow Model and 2010 Hydrogeological Model predict consistent behaviours in the evolutions for water levels and fluxes through the waste. LLW Repository Ltd demonstrates that, despite using a much coarser discretisation, the 2010 Compartment Flow Model predicts a hydrogeological behaviour consistent with the detailed 3D model. Downstream flows in the regional groundwater in the assessment model, which are represented by 1D pipes, are characterised by the flows calculated in unit B3 using the 3D model.</p> <p>PAR_003.1 – Issue not relevant</p> <p>Agreed</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		number is 10 with NX = 20.		
PAR_004	Emergent land dimensions	<p>PAR_004.1</p> <p>Provide the rationale for the choice of the values of sea level in the different altered states, and explain how values have been determined for the extent to which changes in sea level alter the geographical extent of the biosphere, especially the dimensions of emergent land, for each altered state. (See also Recommendation B_BIO_002.1.)</p> <p>PAR_004.2</p> <p>Determine bounds on emergent land dimensions and undertake sensitivity analyses based on these bounds to determine the significance of emergent land dimensions to risk.</p>	<p>PAR_004.1 – Accepted / addressed by work since 2002</p> <p>We have undertaken further work in relation to changes in sea level as a consequence of climate evolution and other effects (Thorne and Kane 2007).</p> <p>PAR_004.2 – Rejected / not needed</p> <p>Impacts to future occupiers of emergent land are not now a main concern because of the expected erosion of the facility. Therefore, the case will be considered as a 'what if', which must be largely hypothetical. Detailed underpinning of the assumptions is neither practicable nor necessary.</p>	<p>PAR_004.1 and PAR_004.2 – Issues not relevant</p> <p>Following the analysis of climate and sea level change presented by Thorne and Kane (2007) and Thorne (2009), the emergence of land created by falling sea levels prior to site destruction is no longer considered a credible scenario.</p> <p>Also see BIO_011.2 and BIO_011.</p>
PAR_005	Hydrologically effective rainfall (HER) and recharge	<p>PAR_005.1</p> <p>Assess the effects of uncertainty in HER for future climate states, and the uncertainties in the proportion of HER assumed to enter the groundwater systems and the</p>	<p>PAR_005.1 – Accepted / to be addressed in the 2011 ESC</p> <p>We agree that this is an important consideration, which will be considered in modelling for the 2011 ESC.</p>	<p>PAR_005.1 – Issue closed with recommendation</p> <p>LLW Repository Ltd assumed that there is a 13% increase in rainfall (and hence HER and recharge) in the expected natural evolution scenario due to climate evolution from 2080. No increase is modelled in the delayed coastal erosion scenario. According to Hartley et al.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		surface waters.		<p>(2011), substantiation for the increase of 13% is provided by Thorne (2010). However, this reference was not supplied as part of the ESC submission.</p> <p>The water budget is reviewed in Hartley et al. (2011) but there is no discussion of uncertainties in HER or the proportions that form recharge or run-off. A data management form for HER is not included in the compilation included in the 2011 ESC submission (LLW Repository Ltd 2011). We recommend that LLW Repository Ltd uses data management forms (or appropriate alternatives) to record all data used in the assessment calculations, such as HER, to maintain a clear audit trail (Recommendation SCM18).</p> <p>See also GEO_017.1 and BIO_008.1.</p>
PAR_006	Groundwater discharge zones	<p>PAR_006.1</p> <p>Present the rationale for the subjective judgments made in selecting the best-estimate coastal discharge distributions and present the uncertainty in these distributions. The sensitivity of risk to assumptions about discharge distributions should be investigated.</p> <p>PAR_006.2</p> <p>Explain in detail the method for decreasing plume cross-sectional area at discharge</p>	<p>PAR_006.1 and 006.2 – No longer relevant.</p> <p>These are detailed technical comments relevant to the approach used in the 2002 PCSC. We consider that the recommendations have been superseded because new approaches will be used in the ESC.</p>	<p>PAR_006.1 and PAR_006.2 – Issues closed</p> <p>The discharge zone for the groundwater pathway is taken to be the inter-tidal region of the Drigg beach and is substantiated as being where unit B3 outcrops (Hartley et al. 2011; Kelly et al. 2011).</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		nodes, and test and support or, if necessary, replace the approach with a more detailed contaminant plume migration analysis. (See also Recommendation GEO_010.1.)		
PAR_007	Radon accumulation in building following intrusion	<p>PAR_007.1 Build on comments in DIS-006. Present a firmer basis for the 10% waste material in soil explaining why this is applicable to buildings and why waste materials could not be considered to be applied as soil improvers.</p> <p>PAR_007.2 Build on GAS_003.9 and DP094b.2, but with a focus on transport through 'soil' rather than cap. Explain why radon transport is always diffusion controlled, and for example why advective transport within bulk gas flow from underlying bulk waste is not considered.</p> <p>PAR_007.3 Justify the 'three minute' radon travel time from the source into the house more robustly.</p>	<p>PAR_007.1 – No longer relevant We agree this factor is arbitrary and was related to an assumption that growing of crops on a waste-soil would be important. In the 2008 update (Sumerling 2008), we dispensed with this dilution allowing a dwelling to be constructed on waste-cap spoil.</p> <p>PAR_007.2 – Accepted / Including in more recent work and to be included in the 2011 ESC Work is currently in hand to assess the migration of radon from disposed waste through cap materials including the soil fill.</p> <p>PAR_007.3 – No longer relevant The empirical model illustrated</p>	<p>PAR_007.1 – Issue closed We agree in the context of land below buildings, but note that the 10% factor continues to be used for land used to grow crops after human intrusion, and requires adequate substantiation for that purpose.</p> <p>PAR_007.2 – Issue subsumed into IRF ESC-TQ-INF-035 If the gas vent is not connected to atmosphere (or there is no vent), then release of radon will be dominated by diffusion through cap materials. If vents are constructed or cracks develop, then advection dominates. LLW Repository Ltd has considered both mechanisms in the 2011 ESC. We sought additional information on the flux and emanation of radon through an intact and eroded cap in IRF ESC-TQ-INF-035. LLW Repository Ltd appropriately addressed this TQ.</p> <p>PAR_007.3 – Issue closed Agreed.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
			in Sumerling (2008) avoids the need for this parameter.	
PAR_008	Coastal erosion, exposure of individuals, and residence time of waste on beach	<p>PAR_008.1 Underpin the basis for the residence time and justify why a homogeneous distribution of waste material in sand is reasonable. This is related to BIO_002.1, which recommends that BNFL should justify the modelling of compartments and the compartment sizes used in the Biosphere Model during each system state.</p> <p>PAR_008.2 Justify the basis for the dust loading ($3.5 \times 10^{-8} \text{ kg m}^{-3}$), inadvertent ingestion of contaminated sand ($10^{-4} \text{ kg m}^{-3}$), and assumed distance from source (1 to 10 m) in an absolute and/or relative sense compared with the land-based scenarios.</p> <p>PAR_008.3 Based on PAR_007.3. Justify the 'three minute' radon travel time from the source into the beach dwelling more robustly, and the choice of the same</p>	<p>PAR_008.1 – Accepted / Including in more recent work and to be included in the 2011 ESC</p> <p>Homogeneous distribution is reasonable assuming exposure is to a PEG using the beach area beneath the repository.</p> <p>We are planning to improve our models of exposure that may occur during erosion of the facility taking account of heterogeneity in the waste and differential dispersion of waste materials according to more detailed study of coastal erosion processes.</p> <p>PAR_008.2 – Accepted / work completed</p> <p>PEG parameters have been reviewed and basis established, see Thorne (2007).</p> <p>PAR_008.3 – No longer relevant</p> <p>The empirical model illustrated in Sumerling (2008) avoids the need for the 'three minute'</p>	<p>PAR_008.1 – Issue closed - subsumed into IRFs ESC-RI-ASO-010</p> <p>LLW Repository Ltd has presented an updated conceptualisation of coastal erosion in the 2011 ESC (Towler et al. 2011). We queried the representation of inventory heterogeneity for calculation of coastal erosion impacts in IRF ESC-RI-ASO-010. Subsequent work by LLW Repository Ltd satisfactorily addressed this issue, allowing the IRF to be closed.</p> <p>PAR_008.2 – Issue closed</p> <p>We consider that this IAF has been addressed by the review of PEG habits (Thorne 2007, 2009).</p> <p>PAR_008.3 – Issue closed</p> <p>Agreed.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		diffusion coefficient as for the soil applied in the equivalent land-based scenario (especially relevant for Rn-220).	parameter. Other factors mitigate against radon exposure for the beach hut case.	
PAR_009	Doses received by future site occupants	<p>PAR_009.1</p> <p>Justify the basis for the assumption that the concentration of contaminants in bulk soil is a reasonable approximation for the concentration in suspendable solids.</p>	<p>PAR_009.1 – Partly accepted / to be reconsidered in the 2011 ESC</p> <p>We consider that the assumption is a reasonable one for the purposes of assessment. Further evaluation of the assumption would require a detailed understanding of the distribution of radionuclides within the waste or soil at future times. We will reconsider this for any cases in which particulate inhalation is the dominant exposure mode.</p>	<p>PAR_009.1 – Issue closed - subsumed into IRFs ESC-RI-ASO-010 and ESC-RI-ASO-011</p> <p>Ingestion of undiluted particulates of waste has been satisfactorily addressed in the responses to IRF ESC-RI-ASO-010 (coastal erosion) and IRF ESC-RI-ASO-011 (human intrusion). These IRFs are closed.</p>

References to Appendix 10

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16. Appendix 11. OESC IAFs

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
OESC_001	Optimisation and Best Practicable Means	<p>OESC_001.1</p> <p>The Agency expects BNFL to provide a clear commitment to consideration and evaluation of potential mitigation or remedial measures in support of risk management and optimisation at the Drigg Facility, including the trench disposals. The presence of uncertainties and the absence of fully quantified data do not justify a decision to delay this exercise.</p>	<p>OESC_001.1 – Accepted / work mainly complete</p> <p>A general consideration of risk management options is reported in Edwards and Alexander (2005). This has been extended by more detailed work on each of the most promising options as summarised in R2S9, Volume 2 (Baker et al. 2008b).</p> <p>Detailed work related to the impacts of selective retrieval of higher activity waste is in hand, see section 4.3 of the 'Approach to 2011 ESC' (Baker et al. 2008a).</p>	<p>OESC_001.1 – Issue closed</p> <p>A comprehensive optimisation case has been made for the treatment management of historical disposals including addressing the issue of selective retrievals. The 2011 ESC contains a much broader range of options than previous assessments. Our review of the application of optimisation to the LLWR is presented in Environment Agency (2015a).</p> <p>Also see our response on COR_003.</p>
OESC_002	Radiological protection and dose constraint	No recommendations made for this IAF.	No recommendation.	Agreed
OESC_003	Definition of exposed groups	<p>OESC_003.1</p> <p>The dose assessment for the Drigg stream considers doses to infants from consumption of milk from cows drinking Drigg stream water and a limited consumption of Drigg stream water by children.</p>	<p>OESC_003.1 – To be re-examined in the 2011 ESC</p> <p>The only realistic pathway at the present day is consumption of milk and meat from cattle drinking from the Drigg stream. The consideration of drinking water is precautionary. For the</p>	<p>OESC_003.1 and OESC_003.2 – Issues closed - subsumed into IRF ESC-RI-ASO-014</p> <p>The exposed groups should reflect the current view of the discharge pathways into streams and the exposure pathways that exist or are reasonably foreseeable. To a significant extent this had been addressed in the 2011 ESC, for example a broader range of PEGs has been</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>This limited assessment is not sufficient and the Agency expects the inclusion of more pathways (in particular animal products) and consideration of a wider range of age groups where appropriate. The Agency expects BNFL to document a comprehensive assessment of potential exposure routes and to ensure that the results of this assessment are applied consistently in the dose assessments for each of the pathways.</p> <p>OESC_003.2</p> <p>For the airborne release pathway, it is not unreasonable that Properties 1 and 2 could grow their own vegetables and therefore their ingestion dose could have been considered, in addition to assessing the dose to Property 3 (the nearest farm). It is recommended that BNFL evaluate the significance of including Properties 1 and 2 as the critical group.</p>	<p>2011 ESC we will undertake of an assessment of all pathways that can reasonably be conceived at the present day. Irrigation is not a sustainable use for the stream.</p> <p>OESC_003.2 – Partly accepted / to be re-examined in the 2011 ESC</p> <p>To be examined in 2011 ESC.</p>	<p>considered. However, as doses of $50 \mu\text{Sv y}^{-1}$ or higher are presented as possible within the 2011 ESC during the period of authorisation, we were concerned that calculated doses may not decline to below $20 \mu\text{Sv y}^{-1}$ by the start of the post-closure phase.</p> <p>We asked LLW Repository Ltd to identify whether there are candidate critical groups who may be exposed to more than one exposure pathway and assess how changes of group composition with time may affect exposure and doses (IRF ESC-RI-ASO-014). Additional assessment presented by LLW Repository Ltd confirmed that calculated doses were below $20 \mu\text{Sv y}^{-1}$ (Sumerling and Jackson 2013).</p>
OESC_004	Scope, purpose and	<p>OESC_004.1</p> <p>The Agency expects BNFL to</p>	<p>OESC_004.1 – Accepted / to be addressed in the 2011 ESC</p>	<p>OESC_004.1 – Issue carried through to ESC-FI-006</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
	objectives of the OESC	<p>define the objectives for the OESC clearly, and to address the following:</p> <p>the questions that the OESC is attempting to answer;</p> <p>how and where the GRA Principles and Requirements are addressed;</p> <p>the broad methodological approach adopted for the dose assessments;</p> <p>whether the empirical data are of sufficient quality to justify the modelling approach;</p> <p>bias, uncertainty and variability in the choice of assumptions and data;</p> <p>how the OESC output influences site strategy and operations.</p>	<p>We accept the 2002 OESC was not clear in its presentation and completeness of argument. In the 2011 ESC the OESC and PCSC will be blended to form a continuous assessment from the present day (when protection is assured through compliance with authorised discharges and confirmed by monitoring) to the post-authorisation conditions (when protection is estimated through modelling). Our approach is outlined in section 5.2 of the 'Approach to 2011 ESC' (Baker et al. 2008a).</p>	<p>The link between period of authorisation and post-closure timescales has been 'blended' in the 2011 ESC, but we raised some remaining concerns over the integration between the period of authorisation and long-term (post- closure) assessments for the groundwater pathway in IRF ESC-TQ-ASO-008. Although we understand the reasons for separate period of authorisation and post-closure dose assessments to meet the requirements of the GRA, we were concerned that inconsistent assumptions were used in these assessments.</p> <p>Graphs of combined impacts for the period of authorisation and post-closure period presented by Baker (2013) showed that the total radiological risk is similar at the end of the period of authorisation assessment and at the start of the post-closure assessment. However, there are a number of trends that correlate less well, for example, earlier breakthrough of radionuclides such as Np-237 and Pb-210 is seen during the period of authorisation. Given that calculated future risks are below the risk guidance level for both scenarios (by over an order of magnitude by the end of the period of authorisation) we considered this acceptable, although we would expect better integration in future assessments (see Recommendation ASS2).</p> <p>The correlation between the period of authorisation and post-closure non-radiological assessments was less good. Although the overall assessment outcome was considered</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
				acceptable, we remain concerned that the assessment did not properly take into account the cumulative environmental impact of releases of non-radioactive contaminants to groundwater. This issue is being taken forward via ESC-FI-006.
OESC_005	Quality assurance and supply of information	<p>OESC_005.1 The Agency requires demonstration of the suitability of the QA system and evidence of its implementation in order to gain confidence in the quality of the OESC. Therefore the Agency requires BNFL to provide further information on the overall quality system and project specific procedures and instructions.</p> <p>OESC_005.2 The cross-linking between the OESC and PCSC needs significant improvement and BNFL should consider the benefits of combining the OESC and PCSC assessments in future.</p> <p>OESC_005.3 The information supplied on the waste inventory gives a misleading impression of the</p>	<p>OESC_005.1 – Accepted / to be included in the 2011 ESC Development of the ESC is carried out under LLW Repository Ltd's QA system, which meets the requirements of ISO 9001. Appropriate subsidiary procedures, specific to the ESC Project are being put in place. See also response to COR_011.</p> <p>OESC_005.2 – Accepted / to be addressed in the 2011 ESC We accept this, see response to OESC_004.1.</p> <p>OESC_005.3 – Accepted / underpinning work is in place The variety/heterogeneity of historic disposed wastes will be qualitatively described in the 2011 ESC. The necessary underpinning work has been undertaken (Lennon et al.</p>	<p>OESC_005.1 – Issue closed The 2011 ESC presented an integrated safety case covering both the period of authorisation and post-closure period in a consistent manner, and using the same quality assurance systems. In general, we consider that the quality assurance procedures were robust and of good quality. Also see IAF CORE_011.</p> <p>OESC_005.2 - Issue carried through to ESC-FI-006 As discussed under IAF OESC_004, although the link between period of authorisation and post-closure timescales has been ‘blended’ in the 2011 ESC, we had some remaining concerns over the integration between the period of authorisation and long-term (post-closure) assessments for the groundwater pathway (IRF ESC-TQ-ASO-008). We believe that these differences are not significant for the radiological assessment, but some remaining concerns relating to the non-radiological assessment are being taken forward via ESC-FI-006. We would expect better integration in future assessments (see Recommendation ASS2).</p>

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		<p>characteristics for the disposed wastes. It is recommended that the variety/heterogeneity of historic disposed wastes is qualitatively described in the OESC.</p> <p>OESC_005.4</p> <p>If the OESC is meant to read as a stand-alone document then a good set of drawings and figures should accompany the text to aid understanding.</p>	<p>2008). However, the connection of variety/heterogeneity of historic disposed wastes to the OESC is not clear.</p> <p>OESC_005.4 – Accepted / to be addressed in the 2011 ESC</p> <p>Details of the presentation of the OESC within the 2011 ESC are not fixed at this time but we accept the underlying criticism.</p>	<p>OESC_005.3 - Issue closed</p> <p>As the period of authorisation assessment is more fully integrated into the 2011 ESC, this issue is not directly relevant. As discussed under SDE_008, LLW Repository Ltd, as part of the 2011 ESC, has carried out a substantial amount of work to improve the derivation of the inventory including the use of RECALL interviews. This work has substantially improved the understanding of the whole range of waste items disposed to the trenches.</p> <p>OESC_005.4 - Issue closed</p> <p>This issue is not directly relevant as a standalone OESC is not presented. Overall, figures and drawings are improved in the 2011 ESC.</p>
OESC_006	Minimising radionuclide releases via the contaminant plumes	<p>OESC_006.1</p> <p>There is a need for a better presentation and fuller analysis of the evolution of groundwater concentrations versus time. If a model is to be used to support the safety argument that no intervention or mitigation measures are necessary, then agreement needs to be demonstrated between the time variations of concentrations in the plume and the model. In developing the arguments, due account</p>	<p>OESC_006.1 – Several connected points here that are partly accepted and will be addressed in the 2011 ESC</p> <p>We do not agree that detailed modelling of the contaminant plume will impact on decisions related intervention and mitigation, as such decisions are based on more general and robust arguments.</p> <p>However, the activities of tritium in groundwater are a marker of the potential for migration from the Trenches;</p>	<p>OESC_006.1 – Issue carried through to ESC-FI-002</p> <p>LLW Repository Ltd acknowledges that tritium in groundwater is a marker for the potential for contaminant migration from the trenches. Environmental monitoring indicates that concentrations of tritium are declining with time, suggesting that the source of the radionuclide in the trenches is much decreased since the early 1990s (LLW Repository Ltd 2011a). Tritium in groundwater appears to be gradually dispersing, migrating mainly to the south, and entering the regional groundwater. Contaminants in the regional groundwater will ultimately discharge to the sea.</p>

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		<p>should be taken of the localisation of the contamination (as a result of variability in the Quaternary sediments).</p> <p>OESC_006.2</p> <p>In the absence of a convincing argument that doses from tritium and other soluble radionuclides would be less than 20 µSv per year, a demonstration of optimisation is required. This should include (but not be limited to) consideration of the following:</p> <ul style="list-style-type: none"> should the repository cap be constructed earlier than envisaged? should additional engineered barriers be installed to prevent discharge into the sea? <p>OESC_006.3</p> <p>The Agency expects BNFL to explain and resolve the apparent discrepancy between the date of the main disposals of tritium phone dials in Trench 6 (~1983/84) and the date of the modelled</p>	<p>as such we accept that further work to reconcile observed tritium concentration and groundwater modelling could be helpful and will form part of the 2011 ESC.</p> <p>OESC_006.2</p> <p>The appropriate guidance level for the period of authorisation is 0.3 mSv y⁻¹; we do not agree that levels above 20 µSv y⁻¹ imply a specific requirement for optimisation. Rather it must be shown that the levels will reduce to 20 µSv y⁻¹ or below at a time such as withdrawal of controls is planned.</p> <p>OESC_006.3</p> <p>See response to OESC_006.1.</p> <p>OESC_006.4</p> <p>See response to OESC_006.2.</p>	<p>There is no evidence of surface discharges of tritium, other than the historical pathway to the railway drain. The cut-off wall is providing protection to the east. We consider it important that LLW Repository Ltd continues monitoring of tritium (ESC-FI-002).</p> <p>OESC_006.2 – Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>We note that, although the 20 µSv y⁻¹ criterion alluded to in this recommendation does not appear in the 2009 GRA for near-surface disposal facilities (Environment Agency et al 2009), it is cited in supplementary guidance to the GRA related to the implementation of the Groundwater Directive (Environment Agency 2013). This supplementary guidance was issued after LLW Repository Ltd provided its response to our IAF recommendations. It states that the radiation dose to members of the public through the groundwater pathway during the period of authorisation of the facility should be consistent with, or lower than, a dose guidance level of 20 µSv y⁻¹. The optimisation requirement (GRA Requirement R8) does not just apply above 20 µSv y⁻¹; rather it applies at any level of dose. In principle, LLW Repository Ltd is required to demonstrate that doses from the contaminant plumes are ALARA. In practice, however, the comments on existing facilities in paragraph 3.5.8 of the 2009 GRA may be relevant to such a demonstration.</p> <p>There is no evidence that tritiated groundwater</p>

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		<p>peak tritium dose (~1980). OESC_006.4</p> <p>Present an assessment of the best practicable means for minimising radionuclide releases via the contaminant plumes.</p>		<p>releases are causing any harm at the moment. Furthermore, the land between the disposal area and the coast is currently a Site of Special Scientific Interest and a Special Area of Conservation, so that there is unlikely to be any development that would include a water abstraction well that might intersect tritium contaminated groundwater. Nevertheless, the possibility that tritium contaminated groundwater could be abstracted from an offsite borehole (assumed to be located between the site and the coast) has been examined indicating a potential dose from tritium (via the well abstraction pathway) would be a maximum of $3 \mu\text{Sv y}^{-1}$ (falling by more than an order of magnitude by 2050) (Sumerling and Jackson 2013).</p> <p>As discussed under IAF CAP_005.2, recent investigations have identified a significant difference between predicted and measured performance of the interim trench cap. As a result of a subsequent BAT study to assess options for improving the performance of the interim cap (Paulley et al. 2012), LLW Repository Ltd implemented a programme of repairs that is designed to reduce infiltration through the interim trench cap. During the repair work, additional failures within the cap were identified. At the time of writing LLW Repository Ltd is reassessing its strategy for making the necessary improvements. We will continue to require LLW Repository Ltd to implement the BAT for the management of the interim trench cap prior to installation of the final cap.</p>

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				<p>We will require LLW Repository Ltd to put in place appropriate monitoring to assess any changes to the performance of the trench cap. This issue is being taken forward through FIs ESC-FI-001 and ESC-FI-027.</p> <p>OESC_006.3 – Issue closed</p> <p>This discrepancy in data is not reported in the 2011 ESC.</p> <p>OESC_006.4 – Issue carried through to ESC-FI-001 and ESC-FI-027</p> <p>LLW Repository Ltd has assessed the feasibility of remediation of the trenches, including selective retrievals of trench waste, in the optimisation studies supporting the 2011 ESC (LLW Repository Ltd 2011b). However, as discussed under OESC_006.2, the company is reassessing its strategy for making the necessary improvements to the interim trench cap and demonstrating the use of BAT. Our requirements for optimisation of the cap are set out in FIs ESC-FI-001 and ESC-FI-027.</p>
OESC_007	Site investigations, facility design and construction	<p>OESC_007.1</p> <p>The Agency expects BNFL to document an evaluation of mitigation measures to minimise the impact of potential releases from the 'uncapped' bays to the environment in support of Condition 4 of the Authorisation and as part of</p>	<p>OESC_007.1 – Rejected (We assume that the recommendation refers to 'Schedule 4' of the Authorisation?)</p> <p>The drainage from Vault 8 (currently 'uncapped') is primarily rainwater with very low concentrations of nuclides</p>	<p>OESC_007.1 – Issue carried through to ESC-FI-001, ESC-FI-025 and ESC-FI-027</p> <p>In 2011 LLW Repository Ltd undertook an inspection of the (uncapped) ISO freight containers in Vault 8 and Vault 9 and made a number of observations regarding their integrity, and the consequent potential for future releases. We attended parts of this inspection and have considered the resulting outputs (Environment</p>

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		<p>an overall risk management programme.</p> <p>OESC_007.2</p> <p>The Agency expects BNFL to document an indication of what ground conditions would be considered unsuitable for Vault 9 and what alternative designs might be implemented in the case of expected conditions not being met.</p> <p>OESC_007.3</p> <p>The Agency expects BNFL to document more technical detail on the site development plans or otherwise present a clear correlation with the PCSC Site Development Plan.</p>	<p>and is collected in the holding tanks for discharge to sea compliant with Schedule 4 of the authorisation. No further mitigation is currently envisaged.</p> <p>OESC_007.2 – No longer relevant</p> <p>No longer relevant in that Vault 9 has been built.</p> <p>OESC_007.3 – Accepted / to be addressed in the 2011 ESC</p> <p>We agree that a more detailed description is required of site management and closure plans, and this will form part of the 2011 ESC.</p>	<p>Agency 2015a,b,c).</p> <p>Observations included: vegetation protruding from a number of containers; softening of the grout; bowing of the side walls on a small number of the full height isofreight containers; standing water residing on top of the lids of a significant number of containers; voidage between the underside of the lid of the containers and the upper surface of the grout; and open grout port holes.</p> <p>As a result of these observations LLW Repository Ltd carried out a programme of assessment of container condition and performance assumptions, including analysis of activity concentrations in standing water. This issue was initially raised in IRF ESC-RI-INF-005, which was adequately responded to by LLW Repository Ltd. We are satisfied that significant impacts are not currently occurring as a result of the ‘uncapped’ vaults. However, we consider that improvements can and should be made to ensure protection of the waste and the cap is optimised and so this issue is being taken forward through ESC-FI-001, ESC-FI-025 and ESC-FI-027 to seek a fuller resolution of the issues raised prior to a final cap being placed over the wastes.</p> <p>OESC_007.2 – Issue no longer relevant</p> <p>Agreed.</p> <p>OESC_007.3 – Issue carried through to ESC-FI-026</p>

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				<p>The 2011 ESC presents an adequate Site Development Plan for the current stage of development of the facility. However, we consider that further information and assurance with regards to the final facility design is necessary prior to construction. Additionally, LLW Repository Ltd has identified the need for a substantial engineering forward programme and design justification process in the run up to construction. The design justification process will need to maintain an effective linkage between the developing design and the ESC to demonstrate that the final engineering design is able to meet the required environmental performance specified within the 2011 ESC.</p> <p>Through an IRF (ESC-RO-SUE-009) and an engineering workshop with LLW Repository Ltd, we sought a better understanding of certain key safety design details, engineering assumptions, design approach and substantiation. LLW Repository Ltd identified the need to develop an engineering forward plan, detailing how the facility design would be taken forward to completion, including further optimisation of the engineering and container design.</p> <p>We have reviewed the response to the IRF and the forward engineering programme (Shaw 2013) and conclude that the scope of the programme and proposals are sufficient to address questions we had raised and to deliver a substantiated final design in accordance with the performance requirements of the 2011 ESC. We will continue to work with LLW Repository</p>

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				Ltd to ensure that the programme provides the engineering information necessary to meet our requirements. We have outlined our expectations for this future programme of work in ESC-FI-026.
OESC_008	Waste form and characterisation	<p>OESC_008.1</p> <p>The Agency requires an acknowledgement that BNFL will periodically update the Conditions for Acceptance.</p>	<p>OESC_008.1 – Accepted / work carried out and acknowledgement so given</p> <p>The CFA will be updated as needed based on results of safety cases and operational experience. A comprehensive review of the consistency of the CFA with the 2002 OESC and PCSC was undertaken (Barber et al. 2006). This led to recommendations for future changes to the CFA and Guidance Note (Barber 2006).</p>	<p>OESC_008.1 – Issue closed</p> <p>The 2011 ESC presents WAC that replace the previous CFA. These WAC take the key outcomes of the 2011 ESC and incorporate them into an acceptance framework, which allows LLW Repository Ltd to maintain compliance with the ESC.</p> <p>LLW Repository Ltd presents proposals for updating the WAC (LLW Repository Ltd 2013). The company has taken those proposals that do not require changes to the LLWR environmental permit forward in its most recent WAC (LLW Repository Ltd 2014). The WAC will be subject to update based on a consignor consultation process and agreement with ourselves and will be required to incorporate any additional control measures derived from our ESC review and permitting process. We will require, through the environmental permit, LLW Repository Ltd to continue to maintain and update the WAC in line with the extant ESC and Environmental Permit. LLW Repository Ltd has in place robust procedures which will trigger review of the WAC based both on operational experience and updates to the ESC and information supporting it.</p>

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OESC_009	Monitoring	<p>OESC_009.1 BNFL need to develop and justify an overall monitoring strategy. A monitoring programme is an important element in ensuring that a disposal facility provides the required level of containment, isolation and protection. See for example, Monitoring of Near Surface Disposal Facilities for Radioactive Waste, Safety Report Series No. 35 (IAEA June 2004) and Near Surface Disposal of Radioactive Waste, Safety Standards Series No. WS-R-1 (IAEA 1999).</p> <p>OESC_009.2 The decision-making criteria for interim cap refurbishment should be made transparent in the OESC to increase confidence in the monitoring of cap performance. The results of cap performance to date should also be presented.</p> <p>OESC_009.3 BNFL should acknowledge the possibility of model</p>	<p>OESC_009.1 – Accepted / work is in place</p> <p>We agree the importance of presenting and following an overall monitoring strategy. A review of monitoring requirements has been undertaken leading to the definition of a monitoring programme (Hillary 2008), which has been incorporated into the ESC Lifetime Plan.</p> <p>OESC_009.2 – Rejected / inappropriate</p> <p>We consider that it would not be efficient to provide precise criteria. We will present the results of cap performance as part of the 2011 ESC and indicate the implications with respect to any need for refurbishment.</p> <p>OESC_009.3 – Accepted / to be addressed in the 2011 ESC</p> <p>Accepted and will be addressed in the 2011 ESC.</p>	<p>OESC_009.1 – Issue carried through to ESC-FI-005</p> <p>Requirements for a long-term monitoring strategy are discussed in Hayes et al. (2011). However, we consider that the 2011 ESC did not fully integrate this strategy into the 2011 ESC forward plan so as to demonstrate the long-term performance of the facility. We raised this issue in IRF ESC-RO-SUE-008. On receipt of additional information from LLW Repository Ltd, we were able to close this IRF. However, we require LLW Repository Ltd to collate and integrate monitoring objectives, strategies and procedures in a single document to provide evidence of how the forward monitoring programme will be implemented and developed throughout the period of authorisation and linked to the ESC to reduce uncertainties, where appropriate, in ESC-FI-005.</p> <p>We welcome the development of LLWR specific performance levels for monitoring data in order to identify where actions may need to be taken (LLW Repository Ltd 2011d).</p> <p>OESC_009.2 - Issue closed</p> <p>Work carried out after the submission of the 2011 ESC has indicated that the efficiency of the interim trench cap (the ratio between flows in the perimeter drains and HER) is on average 58%, compared with the design target of 90% (Baker and Shevelan 2012). Average infiltration through the cap is of the order of 300 mm y^{-1} compared with the 50 mm y^{-1} assumed in the 2011 ESC.</p>

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		<p>uncertainty as a contributing reason for the divergence between model output and environmental monitoring data.</p> <p>(See also OESC_006 Minimising radionuclide releases via the contaminant plumes).</p>		<p>The implications of this underestimate on the period of authorisation assessment are discussed in Baker and Shevelan (2012).</p> <p>LLW Repository Ltd carried out a BAT study to assess options for improving the interim cap (Paulley et al. 2012). This study recommended a programme of targeted remediation of the interim cap and monitoring. The company initiated these works in winter 2013 and encountered significant faults in the trench cap membrane. As a result the adopted BAT approach was stopped, with further optimisation and strategy development work planned to take account of the observed membrane conditions. LLW Repository Ltd has stated that it will maintain a BAT approach until the installation of the final engineered cap. When a revised interim cap management strategy is presented, we will review the ability of the proposed strategy to allow ongoing measurement of performance and deliver the required environmental performance until the placement of a final capping system.</p> <p>OESC_009.3 – Issue closed with recommendation</p> <p>Penfold and Paulley (2011) calculate radiological impacts associated with present day discharges from the LLWR and assessed discharges during the period of authorisation. These are compared with other assessment data. For example, calculated present day exposures from consumption of milk were similar to those reported by Environment Agency et al. (2010).</p>

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				<p>The annual dose associated with present day marine discharges was three orders of magnitude lower than regional doses via the marine pathway (Environment Agency et al. 2010), which are noted as being dominated by the contribution of historic activity in sediments, present-day discharges from other nearby nuclear licensed sites like Sellafield and the presence of naturally occurring radioactive materials from the phosphate processing works at Whitehaven.</p> <p>There is no discussion of uncertainty in the models, and the discrepancies in assumed infiltration through the interim cap, identified after submission of the 2011 ESC, means that hypothetical doses associated with ingestion of groundwater during the period of authorisation are underestimated although below the dose guidance level (Baker and Shevelan 2012). Future assessments should take greater account of uncertainties in the period of authorisation (Recommendation ASS1).</p>
OESC_010	Management of uncertainty	<p>OESC_010.1</p> <p>The Agency recommends that BNFL undertake an uncertainty analysis for the quantitative modelling calculations presented in the OESC. This analysis should take account of good practice in the management of uncertainties (see references</p>	<p>OESC_010.1 – Rejected / not relevant</p> <p>During the operational period the case rests mostly on management controls, monitoring and taking action if required. For the 2011 ESC we intend to strengthen the OESC based on these principles. Any quantitative modelling will</p>	<p>OESC_010.1 – Issue closed with recommendation</p> <p>LLW Repository Ltd assesses environmental safety during the period of authorisation through monitoring of discharges and emissions, projected discharges up until closure and modelled environmental impacts resulting from future releases to groundwater. A suitable range of exposure scenarios is considered and some variants are assessed to consider scenario</p>

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		<p>below).</p> <p>OESC_010.2</p> <p>The Agency recommends that BNFL presents a qualitative discussion of uncertainties surrounding the following issues and to assess the level of confidence that can be attached to the results of the dose assessments in view of these:</p> <ul style="list-style-type: none"> coastal erosion (though generally considered unlikely over the next 150 years, it is not an incredible scenario); tritium plumes migrating off-site; inventory records for disposed waste; and site (hydro)geology. 	<p>mainly relate to interpretation of monitoring results.</p> <p>OESC_010.2 – Low relevance</p> <p>These issues are relevant to post-closure performance and will be considered in the 2011 ESC but are not central to the OESC.</p>	<p>variants (for example, with respect to different exposure groups receiving off-site external radiation). However, the assessment model for the groundwater pathway does not consider conceptual model uncertainty or parameter uncertainty, as was done for the post-closure assessment.</p> <p>During our review, we identified a number of uncertainties relating to the period of authorisation assessment that we considered could benefit from further assessment. These include:</p> <ul style="list-style-type: none"> • the reasons for separate assessment models, with differing assumptions, being set up to calculate impacts resulting from future releases to groundwater for the period of authorisation and post-closure periods (IRF ESC-TQ-ASO-008) • representation of uncertainty in the performance of the interim trench cap (see OESC_004.1) • the assumed 100% effectiveness of the vault leachate management system during the period of authorisation (to be addressed in the engineering forward programme, see OESC_007.3) • representation of critical groups who may be exposed to more than one exposure pathway and whose composition may change with time (IRF ESC-RI-ASO-014) <p>Some of these issues have subsequently been addressed to our satisfaction or acceptable</p>

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				<p>forward programmes of work have been put in place. However, we recommend that a more formal analysis of relevant uncertainties during the period of authorisation is carried out in future ESCs (Recommendation ASS1).</p> <p>OESC_010.2 – Issue closed with recommendation</p> <p>We agree with LLW Repository Ltd's comments in relation to coastal erosion. We also note that the 2011 ESC identified and took account of uncertainties associated with historic inventory records for both the trench disposals and Vault 8. This aspect of the IAF can be closed.</p> <p>However, we consider that further assessment of conceptual uncertainty (for example, with respect to the hydrogeological conceptualisation) is required for the period of authorisation assessment. As noted above, we recommend that a more formal analysis of relevant uncertainties during the period of authorisation is carried out in future ESCs (Recommendation ASS1). We note that we have also requested continued monitoring and assessment of the tritium plumes (ESC-FI-002).</p>
OESC_011	Management of bias	<p>OESC_011.1</p> <p>The Agency recommends that uncertainties and potential sources of bias in the data and the modelling assumptions are clearly identified and the extent of this bias explicitly identified</p>	<p>OESC_011.1 – Low relevance See response to OESC_010.1</p> <p>OESC_011.2 – Low relevance Agreed but unspecific as an issue.</p> <p>OESC_011.3 – Partly accepted</p>	<p>OESC_011.1 – Issue closed with recommendation</p> <p>The period of authorisation assessment is fully integrated within the 2011 ESC and documentation of data and assumptions is improved in comparison with the 2002 OESC.</p> <p>We agree that the level of analysis implied by</p>

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		<p>wherever possible throughout the OESC. This can be achieved by making the implicit and unstated assumptions more transparent to the reader.</p> <p>OESC_011.2</p> <p>When presenting summary statements, the Agency recommends they are qualified to reflect the basis on which the conclusions are drawn and the problem-framing assumptions on which they depend.</p> <p>OESC_011.3</p> <p>Information in Section 5 of the OESC on international policy, principles and practice should be evaluated for its relevance and significance to Drigg operations.</p>	<p>/ to be addressed in the 2011 ESC</p> <p>This section 'Radiological protection principles' will be updated to the extent needed. However, the new Health Protection Agency guidance and the near-surface GRA provide more direct guidance.</p>	<p>the recommendation may be inappropriate if the quantitative content is limited, but comments we have made on the presentation and substantiation of data in the 2011 ESC (Environment Agency 2015d) are appropriate to the period of authorisation assessment (Recommendation ASS1).</p> <p>OESC_011.2 – Issue closed</p> <p>Agreed.</p> <p>OESC_011.3 – Issue closed</p> <p>Radiological principles and policy are addressed in the ESC Level 1 report (LLW Repository Ltd 2011c).</p>
OESC_012	Assessment of prospective public doses	<p>OESC_012.1</p> <p>BNFL should justify whether any critical group could be exposed to more than one exposure pathway.</p> <p>OESC_012.2</p> <p>BNFL should provide evidence to support the</p>	<p>OESC_012.1 – Accepted / to be addressed in the 2011 ESC</p> <p>Critical groups are defined with characteristics such as to represent the groups that could be most exposed to a given exposure pathway or set of connected pathways. Where the same group can be</p>	<p>OESC_012.1 – Issue closed - subsumed into IRF ESC-RI-ASO-014</p> <p>As discussed under OESC_003, we asked LLW Repository Ltd to identify whether there are candidate critical groups who may be exposed to more than one exposure pathway and assess how changes of group composition with time may affect exposure and doses (see IRF ESC-RI-ASO-014). Additional assessment presented</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>assertion that there will be no further migration of radioactivity into the Drigg stream over the next 150 years. (Appendix B notes that in heavy rain, the run off from Vault 8 will enter the Drigg Stream. The basic assumption that concentrations in the Drigg Stream in 2050, 2100 and 2150 will be the same as in 2005 (after radioactive decay) may not therefore be valid)</p> <p>OESC_012.3</p> <p>BNFL should assess the possibility of flooding of land either side of the Drigg stream and the consequences for radionuclides in foods to the critical group.</p> <p>OESC_012.4</p> <p>BNFL should consider whether irrigation (using water from the Drigg stream) is reasonable for green veg, root veg and fruit and evaluate the significance of radionuclide ingestion by the critical group from foodstuffs irrigated using water from the</p>	<p>exposed to multiple pathways the total dose will be assessed.</p> <p>OESC_012.2 – Not relevant</p> <p>Any contaminated flow to the Drigg stream will be very small. The stream will be monitored. The assumption of no additional flow is adequate for prospective assessment during the period of authorisation.</p> <p>OESC_012.3 – Not relevant</p> <p>Flooding to the extent it occurs is due to high tide conditions and involves flooding by a mix of marine and freshwater from the River Irt. This is considered in the estuary modelling.</p> <p>OESC_012.4 – Rejected</p> <p>We have done so. The flow is insufficient and seasonal and therefore unsuitable for irrigation</p> <p>OESC_012.5 – Accepted / to be included in the 2011 ESC</p> <p>Accepted. We will present the calculation in this way in the 2011 ESC.</p> <p>OESC_012.6 – Accepted / to be included in the 2011 ESC</p>	<p>by LLW Repository Ltd confirmed that projected doses were below 20 $\mu\text{Sv y}^{-1}$ (Sumerling and Jackson 2013).</p> <p>OESC_012.2 – Issue closed</p> <p>LLW Repository Ltd will continue to monitor the Drigg stream throughout the period of authorisation (expected to be at least 150 years).</p> <p>In order to prevent back up or overflow of vault and trench leachate during extreme rainfall events or as a result of certain pump failure situations the Marine Holding Tank discharge consent (and RSR permit) allows the overflow to Drigg Stream under certain circumstances. Consent NPSWQD002191 defines a number of emergency conditions during which releases of radioactive leachate from the Marine Holding Tank can be made to Drigg stream. They are:</p> <ul style="list-style-type: none"> • When the effluent has risen above an agreed height in the Marine Holding Tank and the storage capacity of Vault 8 has been exceeded. • The inflow rate into the Marine Holding Tank exceeds the pumping rate to the outfall. • The outfall has failed or is blocked. • When electrical power failure occurs and the discharge valve is in the closed position. <p>Marine Holding Tank discharge to the Drigg stream has occurred on one occasion since 1991 when the system was installed. LLW Repository Ltd is required to inform the Environment Agency if this discharge route is</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>Drigg stream. OESC_012.5</p> <p>It would be better to calculate the total effective dose to a child using reasonable inadvertent ingestion rates of water and a bank occupancy rather than the volume of water needed to be consumed to reach the dose constraint.</p> <p>OESC_012.6</p> <p>BNFL should evaluate whether external dose from the stream bank also needs to be allowed for in the Drigg stream critical group. The total dose from the Drigg stream to children can then be calculated for comparison with the appropriate criteria.</p> <p>OESC_012.7</p> <p>BNFL should justify why the PCSC dietary intake assumptions are not consistent with equivalent data published in BNFL's monitoring reports or the Radioactivity in Food and the Environment (RIFE) monitoring reports.</p>	<p>Accepted. We will include the external exposure in the 2011 ESC.</p> <p>OESC_012.7 – Accepted / to be included in the 2011 ESC</p> <p>We will review the dietary intake assumptions for CGs in the 2011 ESC.</p> <p>OESC_012.8 – Accepted / to be included in the 2011 ESC</p> <p>Emissions of dust to atmosphere relate to operations and will cease when operations cease. For the 2011 ESC we will reassess emissions of tritium, carbon-14 and radon.</p>	<p>used. These permitted discharges will comprise of very dilute leachate which is unlikely to result in the further significant contamination of the Drigg Stream. After any permitted discharge, we would expect LLW Repository Ltd to undertake sampling of the Drigg Stream to assess the extent of any impacts.</p> <p>OESC_012.3 – Issue closed</p> <p>Agreed with respect to the adequacy of the estuary modelling.</p> <p>OESC_012.4 – Issue closed</p> <p>Agreed, with respect to current flows (and current projected environmental changes during the period of authorisation). Local land use during the period of authorisation is not likely to include agriculture that requires irrigation because of ownership restrictions and its location. We therefore do not consider the use of the Drigg stream for irrigation to be a reasonable exposure scenario.</p> <p>OESC_012.5 to OESC_12.8 – Issue closed</p> <p>All these issues are considered in the 2011 ESC period of authorisation assessment.</p>

IAF no.	Title	Review Group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>OESC_012.8</p> <p>BNFL should justify why it believes the highest atmospheric emissions are expected to occur over the next 50 years followed by a decline up until closure in 2150 (atmospheric releases may increase after 2050).</p>		

References to Appendix 11

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17. Appendix 12. RAD IAFs

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
RAD_001	Radiological capacity	<p>RAD_001.1</p> <p>Revise the radiological capacity calculations for the repository, having particular regard to the following:</p> <p>(a) Provide adequate justification for the selected performance measure(s) and assumed performance requirements. This should include the use of calculated risk as defined in the GRA to measure performance, consideration of the application of the GRA risk target to existing waste disposals, and the basis for using any performance measures that have not been adopted in UK legislation (for example, the ICRP intervention level for future human actions⁵).</p> <p>(b) Provide clear proposals as to how the Environment</p>	<p>RAD_001.1 – Point c) rejected / Other parts accepted / to be addressed in the 2011 ESC</p> <p>Our approach to addressing radiological capacity issues has been substantially changed from that pursued previously. An outline of our approach is provided in the Safety Case Approach document. In many respects the recommendations in the IAFs have therefore been superseded. Some further commentary is provided below.</p> <p>a) The provision of such justification is clearly important.</p> <p>b) We will provide suggestions and recommendations in the 2011 ESC.</p> <p>c) We suggest that capacities should be reasonable cases rather than the worst case that can be identified. We recognise that the choice of cases is</p>	<p>RAD_001.1 - Issue closed</p> <p>LLW Repository Ltd limits the radiological inventory accepted for disposal to the LLWR using a radiological capacity approach. In the 2011 ESC, the company derived maximum radiological capacity values for each assessment case and each radionuclide that are linked to the appropriate GRA criterion.</p> <p>In order to manage the radiological capacity of the LLWR, LLW Repository Ltd uses the following control mechanisms:</p> <ul style="list-style-type: none"> • forward inventory assessment • a sum of fractions approach for the control of future disposals (IAEA 2003) • comprehensive WAC with associated radionuclide characterisation requirements • waste emplacement strategies controlling the location and positioning of certain waste streams <p>The following addresses the individual questions of RAD_001.1:</p> <p>(a) Performance measures used in the 2011 ESC are appropriate.</p>

⁵ This intervention level is superseded by the dose guidance level range specified in Requirement R7 of the near-surface GRA (Environment Agency et al. 2009).

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>Agency should derive conclusions concerning radiological capacity from the results of calculations. This concerns the existing presentation of a range of results for different scenarios and calculation cases. The potential benefits of a probabilistic treatment of uncertainty might be considered.</p> <p>(c) Base capacities on the highest values of calculated risk over the PCSC assessment timescale.</p> <p>(d) Consider need to derive specific activity limits for key radionuclides based on exposure scenarios where the risk is related to the specific activity (activity per unit mass) over a volume appropriate to the nature of the exposure, rather than to the average activity of the entire volume of waste in the repository, trench or vault.</p> <p>(e) Define PEGs on the basis of reasonable behaviour, and calculate capacities using these PEGs.</p>	<p>subjective and is a subject that we would like to discuss with the Environment Agency.</p> <p>d) We agree that many scenarios constrain the average specific activity on a scale smaller than that of the whole repository.</p> <p>e) Agreed</p> <p>f) We agree that the basis for all parameters needs to be adequately documented.</p> <p>g) Consideration of the appropriate disposal inventory and optimisation studies need to be appropriately linked in our view.</p> <p>h) Agreed.</p>	<p>(b) We worked with LLW Repository Ltd during the development of the 2011 ESC to ensure that the ESC met regulatory expectations and was robustly developed. The radiological capacity calculations presented in the Developments report (LLW Repository Ltd 2013), which supported the permit application, are clearly linked to the assessment results and take into account initial feedback from our review of the 2011 ESC. Thus we consider that this part of the IAF is closed. However, we have queried why LLW Repository Ltd did not use probabilistic calculation results from the groundwater pathway, well scenario in addition to the results from deterministic calculations in its radiological capacity calculations, and have asked for this to be considered further in FI ESC-FI-012.</p> <p>(c) The radiological capacity and derived WAC are based on realistic rather than worst-case scenarios over the period of authorisation and post-authorisation period. The radiological capacity takes account of the complete disruption of the repository by coastal erosion. We consider this approach appropriate and consistent with the GRA.</p> <p>(d) The 2011 ESC demonstrates that controls are required for both the specific activity and the waste form of future disposals, related to:</p> <ul style="list-style-type: none"> • materials that could give rise to higher activity particles during coastal erosion and human intrusion • materials that could give rise to discrete items

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
		<p>(f) Implement strict change control procedures for input data. Parameter values used in the 2002 PCSC should only be updated and changed where there is a clear basis for doing so. The rationale/justification for all changes must be clearly documented. This includes updates to assumptions about the future inventory.</p> <p>(g) Link the radiological capacity calculation results to a comprehensive and holistic risk management/optimisation exercise, particularly for radionuclides that contribute to calculated risks above the GRA risk target.</p> <p>(h) On the basis of the revised capacity calculations, BNGSL should propose appropriate disposal limits, radionuclide groupings, and associated management arrangements to ensure that waste disposals conform with the proposed limits and groupings.</p>		<ul style="list-style-type: none"> • low activity sources • fissile material • the results of the gas, groundwater, coastal erosion and human intrusion pathway assessments <p>Based on the results of the assessment calculations, LLW Repository Ltd presents controls on total inventory (taking into account existing disposals) and on individual consignments (LLW Repository Ltd 2013). The individual consignment limits ensure that heterogeneity on a consignment basis does not lead to inappropriate impacts and allow the use of emplacement strategies, for example, the restriction of waste that will generate significant concentrations of radon from the upper stack positions. The company has also set out additional controls on discrete items and higher activity particles (LLW Repository Ltd 2014).</p> <p>(e) LLW Repository Ltd defined PEGs in the 2011 ESC based on reasonable expected behaviours. The company has defined specific PEGs for the period of repository erosion, which are based on reasonable future beach usage.</p> <p>(f) The 2011 ESC assessment calculations are completely updated from those carried out in 2002. Thus this issue is no longer directly relevant. We review LLW Repository Ltd's data management procedures in Environment Agency (2015).</p> <p>(g) We consider that LLW Repository Ltd has</p>

IAF no.	Title	Review group recommendations	LLW Repository Ltd response to recommendations	EA comments on LLW Repository Ltd's position
				<p>appropriately linked the assessment calculations results to optimisation in the 2011 ESC. We note that, unlike the 2002 PCSC, no scenarios in the 2011 ESC are projected to lead to exceedances of the risk or dose guidance levels.</p> <p>(h) In general, we consider that LLW Repository Ltd has derived a set of radiological limits that are in line with current industry good practice. We are also satisfied that LLW Repository Ltd has put in place adequate plans to implement the WAC and associated procedures</p> <p>We consider that the issues raised in RAD_001.1 have been suitably addressed in the 2011 ESC and subsequent work. We review LLW Repository Ltd's approach to derivation of radiological capacity values and WAC in the 2011 ESC in Environment Agency (2015).</p>

References to Appendix 12

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List of abbreviations

ALARA	As low as reasonably achievable
AP	After present
BAT	Best available techniques
BES	Bentonite enriched soil
BNFL	British Nuclear Fuels Limited
BPEO	Best practicable environmental option
BPM	Best practicable means
CFA	Conditions for acceptance by LLW Repository Ltd of radioactive waste for disposal at the LLWR
CG	Core group
CMU	Conceptual model uncertainty
Defra	Department for Environment, Food and Rural Affairs
DRINK	DRIgg Near field Kinetic (model)
EPA	Engineering performance assessment
EPR10	Environmental Permitting (England and Wales) Regulations 2010, as amended
ESC	Environmental safety case
FEP	Features, events and processes
FI	Forward issue
GRA	Guidance on requirements for authorisation (of near-surface disposal facilities on land for solid radioactive wastes)
GRM	Generalised Repository Model
HER	Hydrologically effective rainfall
IAEA	International Atomic Energy Agency
IAF	Issue assessment form
ICE	Institute for Civil Engineers
ICRP	International Commission on Radiological Protection
INF	Inventory and near field
IPRG	International peer review group
IRF	Issue resolution form
ISO	International Standards Organization
Kd	Partition coefficient or ratio
LLW	Low level waste
LLWR	Low Level Waste Repository near Drigg, Cumbria

LLWTS	Low level waste tracking system
LTP	Lifetime Plan
mSv	Millisievert
NDA	Nuclear Decommissioning Authority
NDAWG	National Dose Assessment Working Group
NNL	National Nuclear Laboratory
O&E	Optimisation and Engineering
OESC	Operational environmental safety case
ONR	Office for Nuclear Regulation
PA	Performance assessment
PCRSA	Post-closure radiological safety assessment
PCSC	Post-closure safety case
PDF	Probability density function
PEG	Potentially exposed groups
PoA	Period of authorisation
PRA	Probabilistic risk assessment
PRG	Peer Review Group
QA	Quality Assurance
R&D	Research and development
RECALL	A programme used to elicit information on disposal practices at the LLWR from individuals with experience in the area
RI	Regulatory issue
RIFE	Radioactivity in food and the environment
RO	Regulatory observation
RSA 93	Radioactive Substances Act 1993 (as amended)
RSP	Repository site procedures
RWM	Radioactive Waste Management Ltd
SAC	Special area of conservation
SCM	Safety case management
SDE	Site development and engineering
SI	International System of Units
SLC	Site Licence Company
SQEP	Suitably qualified and experienced person
SUE	Site understanding and evolution
Sv	Sievert
TQ	Technical query
TVO	Finnish utility Teollisuuden Voima Oyj

WAC	Waste acceptance criteria
µSv	Microsievert

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.
Advective flux	The mass transport of a substance in response to a pressure gradient. The pressure gradient results in movement of groundwater.
Aerobic	An environment or condition where oxygen is present.
Anaerobic	An environment or condition where oxygen is absent.
Anthropogenic	Originating from human activity.
Assessment code	A computer code used to assess the performance of some aspect of a system.
Basal drainage layer	A granular drainage layer located below the base of the vault.
Bath tubing (over-topping)	The phenomenon whereby leachate collects within a disposal facility (e.g. the vaults or trenches) and builds up to such a level that it overflows.
Becquerel (Bq)	Becquerel is the derived SI unit of radioactivity equal to one disintegration per second. Activities are commonly documented in terms of megabecquerels (MBq or 10^6 Bq), gigabecquerels (GBq or 10^9 Bq) and terabecquerels (TBq or 10^{12} Bq).
Best available techniques (BAT)	The latest stage of development (state of art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste.
Biosphere	The part of the earth's crust, waters, and atmosphere that supports life.
Buffer	A solution that is resistant to changes in pH.
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.

Collective dose	Collective dose is the sum of all the effective doses received by an exposed population.
Colloid	A small particle or molecule dispersed in a second medium that has at least one dimension between approximately 1 nm and 1 µm.
Compartment flow model	A compartment-based numerical model of the LLWR near field used to calculate groundwater flows through the near field.
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.
Conditional dose	The total potential dose received assuming a probability of unity of occurrence of the exposure.
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.
Consignor (of waste)	An organisation or person that sends waste to the repository.
Consignment	A consignment is a container or item of waste sent by a waste producer (consignor) to a disposal facility (such as LLWR).
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.
Criticality	A condition in which a sufficient quantity of fissile material is assembled in the right arrangement for a self-sustaining neutron chain reaction to take place.
Cut-off wall	A generic term for a low hydraulic conductivity wall constructed below ground level that is intended to reduce (cut-off) lateral water seepage into or out of part of a site.
Daughter isotope	An isotope that is the product of the radioactive decay of a parent.
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.
Differential settlement	Differential settlement between two adjacent stacks in the vaults or between adjacent locations of waste in the trenches.
Diffusion	Transport of chemical species along a concentration gradient, within a solid, liquid or gaseous phase.

Discrete items	Discrete items are distinct items of waste that may in future be recognisable as unusual or not of natural origin and so could be a focus of curiosity or interest and potentially recovered, recycled or re-used by persons.
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 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 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 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.
Eh	Redox potential, which is a measure of the tendency of a chemical species to acquire electrons and thereby be reduced.
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

Engineered barrier	optimisation measure to minimise the environmental impact of disposals to the LLWR.
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.
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.
External irradiation	External irradiation occurs when all or part of a body is exposed to penetrating radiation from an external source. During exposure, this radiation can be absorbed by the body or it can pass completely through.
Far field	The far field represents the geosphere beyond the near field.
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.
Fracture flow	Preferential flow of water through fractures in a rock mass.
Gamma radiation	Electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous.
Geological strata	A geological stratum is a layer of sedimentary rock that has characteristics that distinguish it from other layers.

Geosphere	The geological formations and subsurface environment through which radionuclides may migrate.
Glaciotectonics	The study of faulting of geological (and glacial) material resulting from the actions of glaciers during ice ages.
Hydraulic gradient	A measure of the change in groundwater head over a given distance.
Groundwater	Water which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil.
Grout port hole	The hole located on the lid of the ISO freight containers, where the grout is pumped into the container to encapsulate the waste.
Gull wing design	A previous repository restoration design incorporating two discrete landforms for the vaults and trenches respectively.
Half life	For a radionuclide, the time taken for the activity to decrease, by a radioactive decay process, to half of its initial value.
High level waste (HLW)	Radioactive waste in which the temperature may rise significantly as a result of its radioactivity, such that this factor has to be taken into account in the design of its storage or disposal facility.
Human intrusion	Any human action that accesses the waste or that damages a barrier providing an environmental safety function after the period of authorisation.
Hydraulic conductivity	A property of soil or rock, that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid.
Infiltration	The process in which a fluid passes into the pores of a solid.
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.
Intermediate level waste (ILW)	Radioactive waste exceeding the upper activity boundaries for low level waste but which does not need its radiogenic heat to be taken into account in the design of disposal facilities.
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.
Internal irradiation	Irradiation of a person from a source of radioactive material within the body following ingestion, inhalation or absorption through wounds.
Intertidal	Of or pertaining to the area between land and sea that is above the low water mark and below the high water mark.
Ion exchange	The process of reciprocal transfer of ions between two media.
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.
Isotope	Any of 2 or more forms of a chemical element, having the same number of protons in the nucleus, that is the same atomic number, but having different numbers of neutrons in the nucleus, that is different atomic weights.
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.
Leach rates	Rate at which material is lost from a solid on contact with water or other solvent.
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.
Lifetime Plan	NDA requires each Site Licence Company to produce a Lifetime Plan for the site. The Lifetime Plan is usually updated every five years. The Lifetime Plan describes all the activities in terms of scope, schedule and cost to be undertaken on the site in the remaining period of its lifecycle until it is closed.
Lithofacies unit	A subdivision of rock layers distinguished on the basis of similar physical characteristics and facies associations. Lithofacies units have been defined to create a regional three-dimensional model of the geology underlying the LLWR.
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.
Matrix flow	Flow of water through the matrix porosity of a soil or rock matrix.
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.
Overtopping (bath-tubbing)	The phenomenon whereby leachate collects within a disposal facility (e.g. the vaults or trenches) and builds up to such a level that it overflows LLW Repository Ltd also uses the term 'bath-tubbing' when referring to this phenomenon.
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.
pH	A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid and higher values more alkaline.
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.
RECALL interviews	A systematic and recorded interview technique carried out by a third party using standard questions. The objective of the RECALL interview is to elicit and record information from the interviewee based on their experiences and knowledge. RECALL was used by LLW Repository Ltd to elicit information on past disposals to the LLWR.
Receptor	Something that could be adversely affected by a contaminant, such as people, an ecological system, property or water body.
Reducing conditions	Conditions that promote the gain of electrons or a decrease in the oxidation state of a molecule, atom or ion.
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 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).
Retardation	A measure of the reduction in solute velocity relative to the velocity of the flowing groundwater caused by processes such as adsorption.
Retrievability	A characteristic of the design of the waste package and/or the disposal facility that facilitates recovery of waste after emplacement.
Risk guidance level	A level of radiological risk from a disposal facility that provides a numerical standard for assessing the environmental safety of the facility after the period of authorisation.
Scenario	One of several possible descriptions of the evolution of the disposal facility and its surroundings from the time of site closure as a result of natural and human-induced, events and processes.
Shielding	Material placed in front or around a radioactive material to reduce the effects of its radiation.
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 (μ Sv) – 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.
Superplasticiser	A chemical added to grout to increase its fluidity and thus enhance its ability to infiltrate voidage within waste packages.
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.
Unsaturated	A volume of material is unsaturated when some or all of the pore space is filled with air.
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.
Very low level waste (VLLW)	Solid radioactive waste with a maximum concentration of 40 MBq te^{-1} of tritium and carbon-14 (in total) and 4 MBq te^{-1} of all other radionuclides.
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.

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