



# Review of LLW Repository Ltd's 2011 environmental safety case: Inventory and near field

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Published by:

Environment Agency  
Horizon House, Deanery Road,  
Bristol BS1 5AH  
Email: [enquiries@environment-agency.gov.uk](mailto:enquiries@environment-agency.gov.uk)  
[www.gov.uk/environment-agency](http://www.gov.uk/environment-agency)

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T: 03708 506506

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# Executive summary

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

Our review of the 2011 ESC is documented in a series of reports. This report covers our review of the inventory and near field areas. In our review, we considered whether the 2011 ESC meets the principles and requirements set out in our guidance on requirements for authorisation of near-surface disposal facilities for solid radioactive waste (GRA). This guidance sets out what we would expect to see in an ESC.

The overall quality of the 2011 ESC submission in the inventory and near field areas is high. We consider the technical work to be of a high standard and well documented. The clarity of the safety arguments is generally good and the supporting information can generally be traced back to source documents. However, we had to request further documents not included in the original 2011 ESC submission to obtain enough information to complete our review.

## Inventory

LLW Repository Ltd assesses existing disposals to the LLWR trenches and Vault 8 with reference to disposal records and the Low Level Waste Tracking System. We consider that LLW Repository Ltd makes good use of available information, although we note that considerable uncertainty remains, in particular associated with older disposals to the trenches. To help address this, LLW Repository Ltd commissioned interviews with past and present employees of the LLWR and consigning sites to identify any waste that may have been disposed to the facility without accurate or detailed records being kept. This exercise provided evidence in support of the derived inventory, although there was evidence that high activity items, individually containing significant levels of radioactivity, may have been disposed of to the trenches.

LLW Repository Ltd bases the forward inventory for potential future disposals to the LLWR on the UK national inventory of radioactive waste. In line with good practice, LLW Repository Ltd assesses a variety of alternative scenarios for the future inventory. This gives us confidence that LLW Repository Ltd understands which waste streams contribute significantly to the presence of key radionuclides and the associated level of uncertainty. We support LLW Repository Ltd's continuing engagement with the Nuclear Decommissioning Authority and waste consignors to reduce this uncertainty.

Significant uncertainty remains in the understanding of the non-radioactive component of the inventory of both past and potential future disposals. LLW Repository Ltd recognises this uncertainty and has used conservative values in the subsequent assessments. We accept the limitations of available information and we encourage LLW Repository Ltd to maintain engagement with the Nuclear Decommissioning Authority and consignors to continue to improve data for the non-radioactive composition of the forward inventory.

In summary, we consider that LLW Repository Ltd demonstrates an adequate understanding of the inventory of past and potential future disposals. This has helped in the preparation of the 2011 ESC and the development of a source term for the supporting assessment calculations. We further consider that the inventory information included in the 2011 ESC appropriately meets the requirements of the GRA and is suitable for informing decisions relating to the future permitting of the LLWR.

## Near field

Within the 2011 ESC LLW Repository Ltd demonstrates significant progress in understanding of both the physical and the biogeochemical evolution of the repository near field.

Understanding of the physical evolution of the near field is closely linked with the performance and evolution of repository engineering. On a site visit in 2011, we observed the degraded condition of some containers of waste in Vault 8. Issues we observed included penetrative corrosion of container lids and walls, softening of the encapsulating grout, vegetation growth in the containers, the presence of water on the containers and the presence of ullage in the waste packages. These issues will have implications on settlement and the performance of the final engineered cap. As a result of the observations made during LLW Repository Ltd's container investigations and our site visit, the company instigated a forward programme of work to assess these issues and their implications, in particular relating to the optimisation of the containers and the effect of voidage within the containers on the behaviour of the cap. We shall monitor progress through our regulatory engagement programme.

The biogeochemical evolution of the near field plays a key role in determining the concentrations of radioactive and non-radioactive contaminants and gases that will be released from the near field. LLW Repository Ltd developed a detailed biogeochemical model of the repository near field to underpin the conceptual understanding of it. We consider that LLW Repository Ltd adequately identified and characterised the main factors liable to affect the biogeochemical evolution of the near field, resulting in a good understanding of how the chemistry of the near field will evolve over the lifetime of the facility. We identified a number of areas of good practice, for example the use of variant cases to investigate the implications of significant uncertainties on the evolution of the near field and the flux of contaminants from the near field.

LLW Repository Ltd is using near field information to underpin proposed changes to the LLWR waste acceptance criteria. Changes include further controls on voidage that, together with emplacement strategies, are designed to limit cap settlement potential. LLW Repository Ltd is also proposing a change to the waste acceptance criteria to allow the disposal of some complexants that could potentially enhance the release of contaminants from the near field. We concluded that the case presented supports these changes, subject to proposed limits and controls. However, to further support the disposal of complexants, we require LLW Repository Ltd to establish a proportionate monitoring programme for complexants and to undertake further engagement with consignors on the nature of complexants disposals.

In summary, we consider that LLW Repository Ltd has demonstrated an adequate understanding of the near field, which adequately supports the 2011 ESC and the development of an understanding of projected contaminant fluxes out of the disposal facility. We further consider that the near field information included in the 2011 ESC appropriately meets the requirements of the GRA and is suitable for informing decisions relating to the future permitting of the LLWR. However, we identified a number of areas where further improvements can be made to make sure that the LLW Repository Ltd's ESC continues to meet the requirements of the GRA.

# Contents

<b>Executive summary</b> .....	<b>3</b>
<b>1. Introduction</b> .....	<b>6</b>
1.1. Introduction.....	6
1.2. The 2011 ESC submission .....	6
1.3. The review process .....	7
1.4. ESC review deliverables.....	9
<b>2. Our review</b> .....	<b>11</b>
2.1. Overview .....	11
2.2. Inventory .....	11
2.2.1. Trench inventory.....	12
2.2.2. Vault 8 inventory.....	15
2.2.3. Forward inventory.....	18
2.2.4. Non-radiological inventory .....	20
2.2.5. Low level waste tracking system .....	22
2.3. Near field.....	24
2.3.1. Physical evolution of the near field .....	24
2.3.2. Chemical and biogeochemical evolution .....	30
2.4. General observations .....	43
2.4.1. Inventory.....	43
2.4.2. Near field .....	44
<b>3. Meeting our requirements</b> .....	<b>45</b>
3.1. Inventory .....	45
3.2. Near field.....	46
<b>4. Conclusions</b> .....	<b>49</b>
<b>5. References</b> .....	<b>51</b>
<b>6. Appendix 1 - Issue Resolution Forms</b> .....	<b>55</b>
6.1. Introduction.....	55
6.2. Inventory and near field Issue Resolution Forms .....	55
<b>7. Appendix 2 - Recommendations</b> .....	<b>58</b>
7.1. Introduction.....	58
7.2. Inventory and near field recommendations .....	58
<b>8. Appendix 3 - Forward Issues</b> .....	<b>62</b>
8.1. Introduction.....	62
8.2. Inventory and near field Forward Issues (FIs).....	63
<b>List of abbreviations</b> .....	<b>67</b>
<b>Glossary</b> .....	<b>69</b>

# 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.

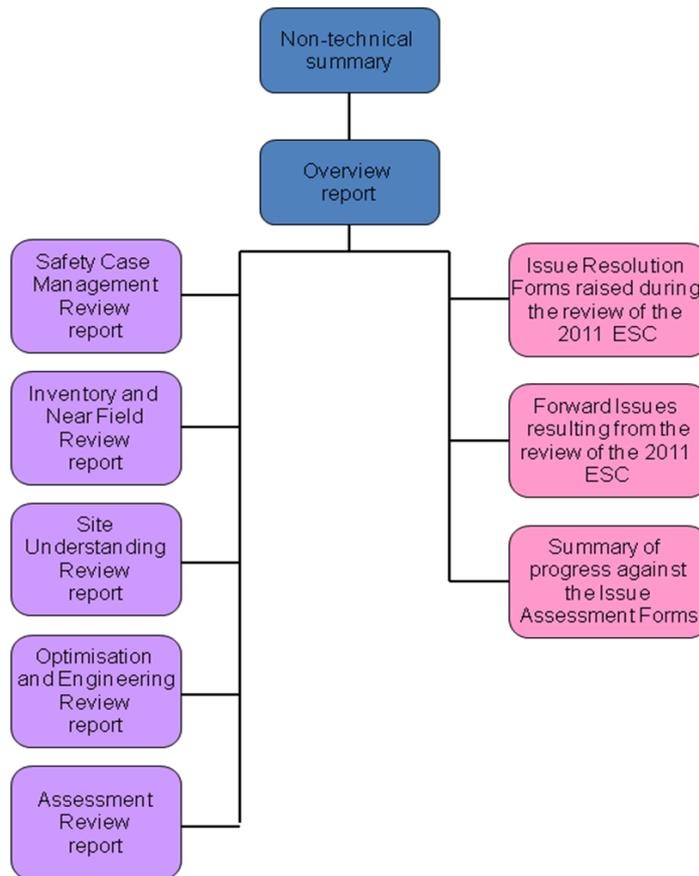
Throughout the review, we also made a number of specific recommendations to LLW Repository Ltd. Recommendations represent areas where we see scope for possible improvement or development, but which are relatively minor in nature relative to FIs. These recommendations are numbered and highlighted in this 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 (2015b); Inventory and Near Field (this report); Site Understanding (Environment Agency 2015c); Optimisation and Engineering (Environment Agency 2015d); and Assessments (Environment Agency 2015e). The IRFs resulting from each of the topic area reports are collated in a standalone report (Environment Agency 2015f).

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

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

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

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

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

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

## 2. Our review

### 2.1. Overview

This report is one of 5 technical assessment reports that support the overview report of our review of the 2011 ESC and cover the main topic areas of the ESC in more detail. It addresses the inventory and near field areas of the 2011 ESC. Our review has focused on the Level 2 and Level 3 reports, our audit of the trench records and our inspection of the International Standards Organisation (ISO) freight containers into which the majority of the vault waste is emplaced. As considered necessary, further documentation has also been requested from LLW Repository Ltd and reviewed as part of this work.

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

LLW Repository Ltd satisfactorily addressed all the IRFs raised in the inventory and near field area during the course of our review and we have closed them. Nevertheless we have identified a series of recommendations and FIs where we consider there is scope for LLW Repository Ltd to make further improvements or pursue developments to the ESC in the future. Whether we made a recommendation or raised a FI depends on the environmental consequences in the absence of any further work. Tables summarising the recommendations and FIs are respectively presented in Appendix 2 and Appendix 3 of this report. We also assessed whether the information presented was sufficient to address technical issues that we raised previously in our assessment of the 2002 ESCs (Galson Sciences Ltd and Environment Agency 2004). A summary of how LLW Repository Ltd has addressed these issues can be found in a separate report (Environment Agency 2015h).

The following sections detail our review, focussing on those areas we deemed important to the 2011 ESC. Our review is split into separate sections covering the inventory and the near field.

### 2.2. Inventory

Our review of the inventory section of the 2011 ESC has covered the following:

- Level 2 inventory report
- 12 Level 3 inventory reports
- 2 Projected Inventory Evaluation Routine (PIER) Spreadsheets and 1 trench spreadsheet

The derivation of the inventory is a key component of the 2011 ESC, as it provides the source term for the dose and risk assessment calculations completed as part of the 2011 ESC. The significance of inventory data and management of the associated uncertainty is discussed in the GRA, in relation to a number of specific requirements:

'The developer/operator will be responsible for all information necessary to support the environmental safety case, and will need to provide it to us in a timely way within an agreed documentation structure so that its relevance to the environmental safety case is clear. The information is likely to include: ... waste inventories and characteristics ...' (GRA paragraph 6.2.34).

'We shall expect the developer/operator to adopt an approach to each requirement that is proportionate to the level of hazard presented by the inventory of waste for disposal in the facility' (GRA paragraph 3.5.3, with a similar sentence in GRA paragraph 6.2.3).

'The level of detail in the environmental safety case should reflect, for example, the stage of development of the facility, what is known and understood about the selected site, the proposed radioactive waste inventory for disposal and what decision has to be made at the time' (GRA paragraph 5.4.6).

'The Regulations also provide for protection of human health and the environment from the hazardous (non-radiological) components of any disposal inventory' (GRA paragraph 9.9.2).

In the 2011 ESC, LLW Repository Ltd presents the inventory as four distinct areas. These are:

- Trench inventory - past disposals between 1959 and 1995
- Disposed Vault 8 inventory - waste disposed of between 1988 to March 2008
- Future inventory - waste disposed to vaults after 31 of March 2008
- Non-radiological inventory - non-radiological waste disposed of to the trenches, Vault 8 and all future vaults

Our review follows a similar format.

### 2.2.1. Trench inventory

Disposals to the trenches took place between 1959 and 1995 and were made under various past authorisations.

The trench inventory provides a substantial component of the total activity in the LLWR, particularly for thorium-232 (Th-232), uranium-235 (U-235) and uranium-238 (U-238). These radionuclides contribute significantly to dose and risk via the groundwater, human intrusion and coastal erosion exposure pathways (although they only contribute significantly to the groundwater pathway impacts in the long-term after the LLWR is likely to be eroded). The greatest uncertainty associated with the disposed repository inventory relates to the trench disposals, when compared with the more recent vault disposals. This reflects the age of the disposals, the contemporary characterisation and management practices and the lack of detailed disposal records (compared to more recent vault disposals). The greatest inventory uncertainty overall is associated with the future inventory, because the use of the repository depends on decisions still to be made by people in the future.

In our review of the 2002 Post-Closure Safety Case (Galson Sciences Ltd and Environment Agency 2004) we concluded that LLW Repository Ltd should make better use of the records available to it for deriving the trench inventory and not solely rely on the use of generic radionuclide fingerprints. In the period leading up to the submission of the 2011 ESC, LLW Repository Ltd has worked to address this, leading to a more accurate representation of the trench inventory.

LLW Repository Ltd's use of further records and more detailed radionuclide fingerprinting in the 2011 ESC has led to a decrease in the estimate of the overall inventory for the key radionuclides in the trenches, except for iodine-129 (I-129), that has increased (LLW Repository Ltd 2011a). In addition, the company has gained an improved understanding of heterogeneity at a large scale (Lennon et al 2008) and at a small scale (Dickinson and Smith 2011) within the trench waste, both in terms of activity and material composition. LLW Repository Ltd has produced heterogeneity maps of the waste in the trenches both for key radionuclides and for important materials such as cellulose (Lennon et al. 2008). This information has fed directly into the 2011 ESC.

#### *Inventory audit*

As part of our review we audited the processes by which the trench inventory was derived (Environment Agency 2012a, b). This was in recognition of the importance of the trench inventory to the 2011 ESC and to provide confidence that LLW Repository Ltd has made best use of disposal records. The audit complemented our review of the 2011 ESC and helped to validate our review outputs.

The audit included information related to 3 trench sub-bays using both records and the back-fitting of waste radionuclide fingerprints<sup>1</sup>, with the aim of tracing how the activity for each was derived.

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<sup>1</sup> 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. This can be used to estimate the quantities of radionuclides for wastestreams of similar composition/origin for which only limited data are available.

The first 2 sub-bays we audited contain high levels of activity primarily associated with the important radionuclides plutonium-239 (Pu-239) in Trench 2 sub-bay 70A and U-234 in Trench 5 sub-bay 24B. Activity in both sub-bays is dominated by one consignment that can be traced back to the individual paper records. The records of this disposal contain useful detail about the consignment and its activity content.

The second sub-bay audited contains lower levels of activity that LLW Repository Ltd has primarily derived by back-fitting waste radionuclide fingerprints, the important radionuclide being chlorine-36 (Cl-36) in Trench 4 sub-bay 36A. The company ascribed this activity to several waste streams, none of which was dominant. Using the volume data from monthly consignments and radionuclide fingerprint data derived from consignments using the process highlighted in Figure 3 of Wareing et al. (2008), we were able to trace data for one waste stream identified by the company. We also asked LLW Repository Ltd to provide us with a further report detailing all the streams that make up the routine consignments for several sub-bays, to provide confidence that the consignments can be traced back to the individual feed streams (Lennon 2013).

These findings provide us with confidence that LLW Repository Ltd has made best use of the records for deriving the trench inventory and that the process for obtaining the inventory is logical and methodical. Although significant uncertainty still exists, we judge that, overall, LLW Repository Ltd has made best use of the available information to derive the inventory for the trenches.

As a result of the audit, we placed a number of actions on LLW Repository Ltd (Environment Agency 2012b). We will monitor and require the company to report progress on these. As a result of the audit, we make the following recommendations to LLW Repository Ltd:

- Much of the knowledge about how the trench inventory has been derived, together with the workings of the Inventory Microsoft Access database used to track the data, resides primarily with a third party contractor. LLW Repository Ltd must make sure that this knowledge is maintained and is available to itself in the future. LLW Repository Ltd should consider bringing this knowledge in house and maintaining this capability internally (**Recommendation INF1**).
- For routine disposals, LLW Repository Ltd uses the Low Level Waste Tracking System (LLWTS) for identifying waste stream fingerprints that best match those streams that were disposed of to the trenches. In future, new and updated radionuclide fingerprints will be added to this tracking system that may give a better match to the trench waste streams. LLW Repository Ltd should consider assessing the application of these new and updated radionuclide fingerprints to the trench inventory as part of any wider review of the trench inventory where it may lead to potential improvements (**Recommendation INF2**).
- LLW Repository Ltd should make sure that the physical location of containers in the vaults is audited and is in agreement with either the current tracking system or proposed new LLWTS. LLW Repository Ltd is addressing this action and is currently undertaking these audits. We recommend that these audits should continue (**Recommendation INF3**).

### **RECALL exercise**

To supplement studies into the inventory LLW Repository Ltd commissioned a 'RECALL exercise'. This entailed interviewing over 30 people that were involved in operations at the LLWR site and Sellafield during the 1960s, 1970s and 1980s in a consistent and controlled manner using an impartial interviewer. The interviews were recorded and the dialogue recorded in written form. The aim of the exercise was to elicit information on disposal practices from individuals with previous operational and other relevant experience, to explore if there was further information that could be used to understand the inventory in the trenches (LLW Repository Ltd 2011a) and to make sure that the inventory presented in the 2011 ESC had not excluded any potentially significant disposals (Hickford and Smith 2011).

The interviews generated 45 issues which LLW Repository Ltd grouped into a number of broad themes:

- unusual dispatches of materials of potential radiological significance
- disposal of materials of non-radiological significance
- disposal of materials of very low or negligible activity

- disposal of material with potentially high radionuclide inventory
- identification of potentially inappropriate disposals
- quality of waste assay

In some cases, the interviewees highlighted that they were not comfortable in providing information with regard to past disposals of potentially high activity items to the trenches. One interviewee highlighted that the new SLC, since taking responsibility for the LLWR, has improved the operation of the facility.

LLW Repository Ltd concluded 'Assessment of the individual issues arising from the RECALL interview process did not find any for which the available evidence suggested a significant and quantifiable impact on the overall inventory in the trenches. No changes to the inventory of disposals to the LLWR trenches have been recommended as an outcome of the RECALL study.' (LLW Repository Ltd 2011a).

In our review we examined 2 LLW Repository Ltd reports (Hickford and Smith 2011, Dickinson and Smith 2011) and also reviewed a sample of the RECALL interviews and LLW Repository Ltd's subsequent documentation of them. We considered the evidence presented within the reports and interviews, as well as whether the company had correctly identified any information of value to the 2011 ESC from the interviews (Environment Agency 2012a, b). We were satisfied that this was the case and agreed with LLW Repository Ltd's conclusions.

We accept that the information provided by the RECALL exercise is not quantifiable and that the position in the trenches of the disposals of issue is not known; however, we consider that it provides useful supporting information to the inventory. In particular it indicates that:

1. Waste of very low or negligible activity was disposed at times, which will tend to bring down the overall radiological inventory of the trenches.
2. There is evidence that some items of waste may have been disposed that carried potentially significant burdens of radioactivity, for example waste arising from the clean-up of alpha and beta contaminated plants disposed of within shielded containers (Dickinson and Smith 2011). Conversely to point 1 above, these disposals are likely to have increased the overall radiological inventory in the trenches and also to have introduced higher activity items, potentially including discrete items<sup>2</sup>, potentially with a significant burden of radioactivity.

We discuss the implications of discrete items bearing a significant burden of radioactivity further in our report on assessments (Environment Agency 2015e), in particular in relation to the exposure of these items following either coastal erosion or human intrusion into the waste in the future. This discussion concludes that the doses and risks presented by such discrete items are acceptable and within criteria defined in the GRA. However, we have also raised a FI (ESC-FI-013) requiring LLW Repository Ltd to consider past disposals of discrete items, assess the possible implications and identify any resulting action required.

We raised a number of queries related to the RECALL interviews within ESC-TQ-INF-004. As part of its response LLW Repository Ltd re-confirmed that it did not consider the further evidence from the RECALL work to have provided evidence of any need to make significant modifications to the overall LLWR inventory and therefore influence any of the assessments completed as part of the 2011 ESC. We accept this conclusion. However, one minor query did remain outstanding from our TQ which related to consideration of the combination of effects from multiple issues arising from the RECALL work for key radionuclides. We do not believe this will have any significant implications, but should be addressed for completeness. We therefore recommend that LLW Repository Ltd addresses query 10 within ESC-TQ-INF-004 (**Recommendation INF4**).

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<sup>2</sup> A 'discrete item' is defined by LLW Repository Ltd as a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling/re-use of materials should the waste item be exposed after repository closure.

It is important that LLW Repository Ltd makes use of environmental monitoring to ensure that any unexpected discharges as a result of past disposals are detected. In our review of the monitoring carried out to support the 2011 ESC (Environment Agency 2015c) we conclude that the programme is adequate for this purpose.

### **Uncertainty**

Due to the nature of the trench disposals, it is essential that the 2011 ESC addresses and takes account of the level of uncertainty in the radiological and non-radiological composition of the waste.

In previous reviews we noted that a limitation of the trench inventory investigations has been the lack of a systematic treatment of uncertainty (Environment Agency 2010). In the 2011 ESC, LLW Repository Ltd has investigated the uncertainty in the quantities present of important radionuclides (U, Th, Pu and radium (Ra) that account for over 90% of the total long-lived activity in the trenches, important to the post closure scenario).

As a result of its investigation, LLW Repository Ltd concluded that, for the trench inventory, an upper bound for radionuclide quantities is an order of magnitude greater than the best estimate (Harper 2011a). LLW Repository Ltd based this conclusion on more detailed consideration of the major waste streams that contribute to the important radionuclides. Other information relevant to assessing the uncertainty came from discussions with waste producers.

To explore LLW Repository Ltd's assessment of the uncertainty associated with disposals of important radionuclides to the trenches, we raised an IRF on uncertainty in the Pu inventory including, in particular, the effect that burn-up will have on the Pu isotope inventory (ESC-TQ-INF-024). In response, LLW Repository Ltd demonstrated that the uncertainty in the Pu inventory does not exceed the order of magnitude presented in the 2011 ESC.

We conclude that, on the basis of information currently available to LLW Repository Ltd, the assumed order of magnitude of uncertainty for the radionuclide components of the trench inventory is reasonable. We accept that this approach provides a level of conservatism appropriate for use in the 2011 ESC assessments.

We note that there will also be significant uncertainty associated with the non-radiological components of the trench inventory. This is addressed in Section 2.2.4 of this report.

Given that much of the trench inventory is derived using radionuclide fingerprint data, we consider that LLW Repository Ltd should consider the use of relevant new and updated radionuclide fingerprint data from future waste streams in future updates of the ESC to reduce the uncertainty in the trench radionuclide inventory (see Recommendation INF2).

Overall, LLW Repository Ltd has completed a significant amount of work to improve the derived inventory for the trenches. In particular, we commend LLW Repository Ltd's use of past records and the RECALL exercise to make sure that the inventory is assessed as accurately as possible. Our audit has provided us with confidence that the processes for deriving the inventory were appropriate.

We note that significant uncertainty remains; perhaps as might be expected for a waste disposal facility with a long history, however, we conclude that LLW Repository Ltd has identified and appropriately taken account of this uncertainty in the subsequent assessment of past waste disposals in the 2011 ESC. We expect LLW Repository Ltd to continue to review the level of uncertainty and make best use of any relevant sources of information that may become available, with the intention of reducing inventory uncertainty as far as is practicable.

We also expect LLW Repository Ltd to have an appropriate monitoring programme in place to help limit and reduce uncertainty and to confirm that the leachate observed is as anticipated (ESC-FI-005).

### **2.2.2. Vault 8 inventory**

Vault 8 has been open for disposal since 1988 and was not full when the 2011 ESC was prepared. Consignments to Vault 8 are classified depending on their location in a waste stack. Waste packages up to a stacking height of 4 are classed as 'disposed', whilst packages located above

this height are classified as being 'stored'. For the purposes of the 2011 ESC, any waste disposals after 31 March 2008 are designated as forward inventory.

However, these designations of waste in Vault 8 are not always clear in the 2011 ESC. We sought clarification on this point through IRF ESC-RO-INF-002. LLW Repository Ltd's response provided satisfactory clarification.

The Vault 8 inventory has been derived from the disposal records in the LLWTS and from data abstracted from both the Waste Inventory Disposition Route Assessment Model (WIDRAM), that is maintained by the National Nuclear Laboratory (NNL) on behalf of the NDA and the 2007 United Kingdom Radioactive Waste Inventory (UKRWI). The quality of these data is superior to that of the trench data and thus the derived inventory is less uncertain.

### *Key radionuclides*

We raised ESC-TQ-INF-021 to seek clarification from LLW Repository Ltd on the significance of americium-241 (Am-241) to the inventory of Vault 8 and the LLWR as a whole. This confirmed that Am-241 within Vault 8 was a significant contributor to the total site Am-241 inventory. The 2011 ESC also identifies that the Cl-36 and carbon-14 (C-14) within Vault 8 contribute significantly to the overall activity in the repository (Harper 2011a). These 2 radionuclides are important contributors to the risks associated with both the groundwater and gas pathways.

### *Waste distribution*

Knowledge of the distribution of waste across Vault 8 is important for gaining an understanding of how the vault waste will evolve and ultimately impact on people and the environment. For example, the distribution of cellulose waste throughout the vault will affect the nature and extent of engineered cap settlement and the distribution of radionuclides may have implications for dose uptake from human intrusion scenarios or following coastal erosion.

As noted in Section 2.2.1, LLW Repository Ltd has much improved its understanding of the location of both key radionuclides and key materials in the trenches (Wareing et al. 2008). However, similar information is not presented for Vault 8 in the 2011 ESC. In future updates of the ESC we would like to see increased use and presentation of Vault 8 inventory information wherever beneficial to the advancement of assessments or presentation of understanding, for example of issues such as waste heterogeneity.

We note that LLW Repository Ltd plans to implement a number of emplacement strategies for future vaults. These strategies are important for ensuring that the proposed LLWR design features behave as expected. For example, an emplacement strategy controlling the quantity of total potential voidage (TPV) in a stack is proposed to minimise the differential settlement across the engineered cap (a 4-high stack of containers will have a limit of 35% TPV per container and a 9-high stack will have a limit of 20% TPV per container) (LLW Repository Ltd 2013a); As part of the engineering forward programme (Shaw 2013) and the proposed Phase 1 implementation plan, LLW Repository Ltd will review this area further in relation to cap performance. Further emplacement strategies are proposed to minimise the risks associated with potential future human intrusion. For example, the placement of radium waste towards the bottom of a stack will minimise the dose received from a human intrusion event (LLW Repository Ltd 2013a). These emplacement strategies have not yet been applied in Vault 8. As part of LLW Repository Ltd's proposals to dispose currently stored waste within Vault 8 and Vault 9, these strategies will need to be considered as part of an overall demonstration of best available techniques (BAT).

To aid in understanding the distribution of waste within past disposals, including Vault 8, where it has a bearing on performance (for example cap settlement or dose impacts) we consider there may be benefits from undertaking further work to 'map' waste distribution. We recommend that LLW Repository Ltd should consider and where benefits are identified, present information on the distribution of key radionuclides and key materials for past disposals. This information may be beneficial in showing how emplacement strategies have been used (ESC-FI-010).

## Non-standard disposals

The current and proposed future practice for the majority of disposals to the vaults is to encapsulate waste within either full, half or a third height ISO freight containers and to dispose of these containers in a series of engineered vaults. However, in a limited number of circumstances LLW Repository Ltd also disposes of waste directly into the vault, or within 'non-standard' containers, often (but not always) followed by the waste being grouted in place in-situ. We define non-standard disposals as disposals to the LLWR vaults not made within the commonly used ISO freight containers. Examples included the direct disposal of cylinders, flasks, ingots or alternative waste containers, an example being Windscale Advanced Gas-cooled Reactor boxes.

From review of the 2011 ESC and also an inspection we completed on the north-west corner of Vault 8, it was not clear to us whether many of these non-standard disposals were grouted internally or if voids were filled with waste. This could have implications for the settlement of the engineered cap (this is considered further in Section 2.3.1) as, dependent on the waste form, it could have a significant bearing on void space within the waste item. Additionally, the 2011 ESC did not provide a comprehensive list of non-standard disposals in Vault 8.

We therefore raised IRFs ESC-RO-INF-003 and 003b to seek further information on the non-standard disposals within Vault 8. LLW Repository Ltd's response demonstrated a thorough understanding of these non-standard disposals and its acceptance and assessment procedures for these items. The company clarified both the range of disposals and whether any non-standard containers or vessels were grouted internally or not. This response addresses our immediate concern, but we expect future updates of the ESC to identify and assess the nature and extent of non-standard disposals in Vault 8 and any future vaults (**Recommendation INF5**).

We note that LLW Repository Ltd identifies the need to consider the implications of the presence of non-standard disposals and their form within assessments of geotechnical robustness and settlement of the cap (Jefferies 2013).

## Uncertainty

In our review of the 2008 Requirement 2 Submission<sup>3</sup>, we requested that LLW Repository Ltd adopts a systematic approach to the treatment of uncertainty in the inventory of disposals (as discussed in Section 2.2.1 with respect to the trenches) (Environment Agency 2010).

The Vault 8 inventory has been derived by assigning stream specific radionuclide fingerprints to waste disposals (Wareing et al. 2008). Radionuclide fingerprints have been coupled with specific activity and materials data, to produce an overall inventory for the vault. We note that the input data for Vault 8 as recorded in the LLWTS are more accurate than for the trenches; as a result of the higher quality information provided over recent years and improved waste characterisation. However, a generic radionuclide fingerprint had to be used for several waste consignments, because they could not be matched with waste streams in the LLWTS. This was particularly the case for some early disposals to Vault 8. We recognise this as a source of uncertainty associated with the Vault 8 inventory, but are satisfied that it has been adequately considered within the overall assessment of uncertainty.

We agree with LLW Repository Ltd that an order of magnitude is sufficient to bound the uncertainty associated with the Vault 8 inventory. In future updates of the ESC, LLW Repository Ltd should consider whether future radionuclide fingerprints are suitably representative of the Vault 8 waste streams currently without a matched radionuclide fingerprint (in an analogous fashion to our recommendation for the trench inventory in Section 2.2.1) (**Recommendation INF6**). We expect future updates of the ESC to improve, where possible, the use of applicable Vault 8 data to improve accuracy and reduce the uncertainty.

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<sup>3</sup> LLW Repository Ltd's permit required them to 'Provide a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events.'

LLW Repository Ltd recognises that assumptions regarding waste density are also a source of uncertainty; '...Where the quantity of waste is given in volume terms, as is generally the case, it becomes necessary to assume the density of the waste' (Small et al. 2011b). We agree with this view. It highlights the need to make sure that information provided by consignors is of good quality and sufficient to inform the developing ESC. Improving waste characterisation information should help to reduce this uncertainty in future iterations of the waste inventory.

We conclude that the inventory derived for Vault 8 is based on more reliable and detailed data than for the trenches and is subject to less uncertainty. We consider it adequate to support the assessments within the 2011 ESC. We expect future iterations of the ESC to continue to enhance understanding of the Vault 8 inventory and its associated uncertainty.

### 2.2.3. Forward inventory

The forward inventory given in the 2011 ESC covers all actual and projected disposals to the LLWR from 31 March 2008 until 2127 (LLW Repository Ltd 2011a). The forward inventory has been derived in 3 distinct stages. Stage 1 involved LLW Repository Ltd identifying all potential LLW arisings that could be disposed of to the LLWR. The waste streams were identified from WIDRAM09. The input data to this database are obtained from the UKRWI 2007 and Waste Accountancy Templates. The latter provide updated estimates of the waste arisings from each of the NDA sites and are produced annually to support site lifetime plans (Harper 2011a, Harper 2011c). The input data from WIDRAM09 was then fed into LLW Repository Ltd's Projected Inventory Evaluation Routine (PIER) model that is then used to derive the forward inventory (Harper 2011c).

In Stage 2 a filter is applied in the PIER model to remove those streams that are unlikely to be disposed of to the LLWR and are likely to be disposed of via alternative routes. An example is contaminated soil from Dounreay that will most likely be disposed of to the LLW disposal facility at Dounreay or managed on the Dounreay site.

The filtered inventory from Stage 2 was then assessed in Stage 3 to identify the process route by which each waste stream will be treated. The waste treatment options are incineration, smelting, compaction and direct disposal without pre-treatment. The primary and secondary waste generated from each of these treatment processes are assumed to be disposed of to the LLWR. The PIER model assesses both the activity and volume of waste to be disposed of to the facility annually and can be used to produce an estimated closure date for each vault.

#### Future inventory cases

LLW Repository Ltd has produced 4 future inventory cases as inputs for assessment in the 2011 ESC (Harper 2011b). These reflect 4 scenarios representing future waste arisings. The 4 cases are summarised in Table 1.

**Table 1 Inventory cases in the 2011 ESC**

Case	Description
A	Reference case, intended as a bounding case for waste identified in the UKRWI
B	Reference case plus the effect of the nuclear new build programme on the LLWR inventory
C	Reference case, but addresses uncertainties in volumes of waste to be disposed of
D	Reference case, but considers the effect of alternative waste routes for some streams associated within land affected by contamination (referred to as contaminated land within the 2011 ESC)

The forward inventory provides the radiological source term used in assessing the risks to human health and the environment. It is therefore a fundamental input to the 2011 ESC. It also provides an essential basis for planning, by projecting the required capacity of the LLWR and estimating repository fill rates and closing dates for each of the vaults. Because LLW Repository Ltd did not attribute probabilities to the variant cases B, C and D (Table 1) when assessing the 2011 ESC we assumed an equal probability of each inventory happening. Overall we consider this approach to be reasonable.

However, we queried the implications of a 'combined case' for the 2011 ESC, where elements of all 3 cases applied (ESC-TQ-INF-020). Through its response to IRF ESC-TQ-INF-020, LLW Repository Ltd considered a 'combined' inventory case (Case E). The main effect of this case is to increase the length of time that the vaults will remain open compared with the reference case (Baker 2013b). For example, Vault 11 could be open from 2030 to 2075, compared with 2027 to 2030 in the reference case. The assessment also demonstrated that there could be significant increases in the activities of C-14, cobalt-60 (Co-60), molybdenum-93 (Mo-93) and calcium-41 (Ca-41), with small increases for other radionuclides in the reference disposal area (RDA). Also a significant reduction in Ra-226 disposals could result from the diversion of contaminated land waste streams away from the LLWR. LLW Repository Ltd assessed the impact of the Case E inventory and found that there were no significant increases to risk associated with the various assessment pathways.

For inventory Case E, LLW Repository Ltd also projected that the potential number of vaults in the extended disposal area (EDA) could be reduced. The company will need to maintain an awareness of the effects of inventory changes on the number of vaults needed and the length of time that they will be open. Keeping vaults open for longer may affect the integrity of containers and, in due course, the capping strategy. In our Optimisation and Engineering report (Environment Agency 2015d), we raised an FI (ESC-FI-025) which seeks further optimisation work specifically addressing the need to protect waste before capping, which will need to take into account the time periods that vaults remain open and therefore waste remains exposed. This aspect of the inventory is discussed further in Section 2.3.1.

### *National inventories*

In deriving the forward inventory, the WIDRAM09 database used data from the 2007 UKRWI to establish a baseline of projected LLW arisings. The 2007 UKRWI was the most up-to-date version that the NDA had published at the time of the data freeze for the 2011 ESC. However, the NDA has since published the 2010 UKRWI. Within IRF ESC-RI-INF-001, we queried the effect this inventory would have on the assessment.

As part of its response, LLW Repository Ltd presented a significant body of further work examining the changes in the 2010 UKRWI and the effects on the 2011 ESC assessments. This information did not form part of the original 2011 ESC submission. In summary the company concluded 'For most key radionuclides, with the exception of Cl-36 and Am-241, the total inventory projected for the vaults within the combined reference and extended disposal area (RDA plus EDA) is less than the inventory assumed in the ESC. However, for C-14, Cl-36, Ca-41 and Mo-93, there is an increase in the inventory associated with the RDA. In part, this reflects a reduction in waste volumes, which extends the operational life of the RDA, bringing some wastes forward from the EDA to the RDA. Assuming the exclusion of two waste streams, for which the inventory is considered erroneous, there is a significant decrease in the Ra-226 inventory that is projected to be disposed in the vaults' (LLW Repository Ltd 2012c). The company also carried out assessments to examine the implications of these changes. In summary LLW Repository Ltd concluded that '...the results presented in this report indicate that adoption of the revised 2010 inventory results in calculated impacts that are similar to those calculated for the 2011 ESC.' (LLW Repository Ltd 2012b). We agree with these assessments.

These assessments give us confidence that there are no significant implications for the 2011 ESC resulting from the update of the 2007 UKRWI to the 2010 UKRWI. We concluded that these inventory updates do not affect any of our overall conclusions on the 2011 ESC.

## Uncertainty

LLW Repository Ltd has identified the major waste streams that will be important in terms of the forward inventory (Baston et al. 2011). Of these waste streams 21 were identified as having significant uncertainty associated with them. The company engaged with the relevant waste consignors with the aim of increasing its understanding and reducing the uncertainty. In several cases this led to a reduction in the assessed level of activity that will be disposed of to the LLWR and an associated reduction in uncertainty. We commend this approach and expect LLW Repository Ltd to continue to engage with both consignors and with the national nuclear LLW strategy to further reduce uncertainties associated with future waste streams. We expect to see this approach expanded to cover the non-radiological components of the forward inventory, particularly for hazardous substances (see Section 2.2.4) (**Recommendation INF7**).

Within the 2011 ESC there are references to 'unknown alpha and beta/gamma' in the forward inventory reference case (Table 5.4 of LLW Repository Ltd 2011a). The implications of this uncertainty for the 2011 ESC are unclear and we question why these unknowns exist, although we also accept that within the reference inventory the contributions from these unknowns are very small and will have limited bearing on assessment outcomes. We encourage LLW Repository Ltd to work with consignors and the NDA to address this specific area of uncertainty (**Recommendation INF8**).

Within IRF ESC-TQ-INF-003 we sought clarification of several statements in the 2011 ESC relating to the forward inventory. LLW Repository Ltd provided satisfactory responses. Of our queries, the uncertainty associated with estimates of Cl-36 in gas-cooled reactor waste was of particular interest (Harper 2011d). These wastes will not be generated for several decades and therefore the uncertainty may remain for a considerable time. Cl-36 is an important radionuclide for the groundwater pathway in the 2011 ESC. We understand that, as part of the UKRWI programme, LLW Repository Ltd is working collaboratively with the NDA to improve the Cl-36 inventory data. We support further engagement between LLW Repository Ltd and both the consignors and the NDA to reduce this uncertainty. We also recommend that the company should maintain an awareness of any developments nationally and internationally that can help reduce the uncertainty associated with the Cl-36 inventory (**Recommendation INF9**).

Overall, we support LLW Repository Ltd's approach to deriving the forward inventory and support its engagement with consignors and the NDA to try to reduce uncertainties and improve the quality of the forward inventory data. LLW Repository Ltd should use all available sources of information in pursuing this approach.

### 2.2.4. Non-radiological inventory

As for the radionuclide inventory, LLW Repository Ltd derived the non-radiological component of the inventory separately for the trenches, Vault 8 and the forward inventory. We expect the non-radiological component of the inventory to be derived with a rigour suitable for meeting Requirement 10 of the GRA '...that the disposal system provides adequate protection against non-radiological hazards' (GRA Paragraph 6.4.1).

## Trenches

Waste disposed of to the trenches came from a number of nuclear and non-nuclear activities, utilising a range of processes. These will have generated a wide range of hazardous and non-hazardous pollutants that will have been disposed of to the LLWR. Past conditions for acceptance required significantly less information on non-radiological components of waste than radiological components and when compared to the information now required. It is well understood that the level of non-radiological information associated with the trenches is far less detailed and more uncertain than the radioactive waste inventory and those wastes disposed of today.

LLW Repository Ltd recognises that there are significant uncertainties associated with the non-radiological trench inventory (Dickinson and Kelly 2011), because:

- several contaminants have been detected in trench pore water for which no data are recorded in the records of disposal
- a significant proportion of the inventory is recorded as having unknown composition

- the physical form of the waste is often not clear from the available information

We also note the possibility that some contaminants may be present that have not been measured in leachate or documented in disposal records. For example, it is possible that thallium and tellurium are present in the trench inventory as a result of their use at the Harwell Research and Development (R&D) facilities, although we have no direct evidence of this.

As part of our review of the 2011 ESC we completed an audit of trench records including a review of non-radiological records from Sellafield and Chapelcross (Environment Agency 2012a and 2012b). This audit confirmed the low level of available trench information on non-radiological disposals and the high level of uncertainty in the data. For example, the information reviewed was at a very low level of detail, often omitting the quantity, form or even type of waste. To illustrate, records often merely stated 'plastics', 'metals', 'gloves', and so on.

LLW Repository Ltd derived the non-radiological component of the trench inventory using an approach similar to that for the radioactive component. This involved abstracting any relevant non-radiological information from the disposal records.

LLW Repository Ltd used an approach which back-fitted fingerprints to derive the non-radiological component of the inventory, based on the assumption that the waste streams identified in the LLWTS are similar to the waste streams disposed of in the trenches. We accept this as a pragmatic approach to deriving the non-radiological component of the trench inventory and probably the best that can be achieved with the available information. However, significant uncertainty remains and needs to be taken account of within the 2011 ESC non-radiological assessments, which we assess elsewhere (Environment Agency 2015e). Here we conclude that this uncertainty is adequately accounted for.

Given that there is limited further information that can be gained from past records of the trench inventory an appropriate means to reduce uncertainties is the use of monitoring, for example of the leachate and groundwater environment. Our review of monitoring carried out in support of the 2011 ESC (Environment Agency 2015c) satisfied us that there is sufficient provision of non-radioactive monitoring and sampling to identify any hazardous and non-hazardous substances present in leachate or groundwater and to aid in reducing uncertainties. This data may be used to better inform the non-radiological hydrogeological risk assessment. As discussed further within Environment Agency (2015c), we raised a FI (ESC-FI-006) which indicates how monitoring may be able to contribute.

We further address how we consider monitoring may be used to reduce uncertainties within Environment Agency (2015c) and ESC-FI-005. To support monitoring of the trenches sufficient leachate collection and monitoring infrastructure is required before and after capping. Within a FI (ESC-FI-023) we ask LLW Repository Ltd to develop a leachate management strategy. An element of the leachate management strategy will be the identification of trench leachate sampling and monitoring requirements, including infrastructure.

As well as influencing the non-radiological hydrogeological risk assessment, uncertainty in the chemical composition of the waste may have wider impacts, for example gas generation and degradation leading to voidage. These issues are considered further in our other reports (Environment Agency 2015d and 2015e) and we are satisfied that uncertainties have been adequately accounted for and have not compromised performance.

Because of the large uncertainties associated with the trench non-radiological inventory we recommend that further consideration be given to options to reduce uncertainty, for example through use of appropriate waste fingerprints (**Recommendation INF10**).

### **Vault 8**

The non-radiological inventory for Vault 8 has primarily been derived from the LLWTS (Dickinson and Kelly 2011). We consider the information derived for Vault 8 to be of much better quality than that derived for the trenches and we consider the understanding presented to be sufficient to support the 2011 ESC assessments. However, we consider that there remains scope for potential improvements, for example in the collation of data supporting the non-radiological hydrogeological risk assessment and for complexants, which are discussed elsewhere. We expect LLW Repository

Ltd to make sure that the LLWTS allows for the appropriate capture of non-radiological information relevant to the 2011 ESC.

A small proportion of the Vault 8 non-radiological inventory has been derived using a back-fitting process similar to that used for the trenches. We expect LLW Repository Ltd to review this inventory component against future waste stream compositions and to refine it where possible (**Recommendation INF11**).

### *Forward inventory*

We note a contradictory statement within the 2011 ESC regarding the forward non-radiological inventory. Dickinson and Kelly (2011) state that the non-radiological inventory of the projected disposals to the LLWR is derived from information held in the 2004 UKRWI. Whereas, the Level 2 inventory document states that the 2007 UKRWI has been used (LLW Repository Ltd 2011a). We expect LLW Repository Ltd to maintain consistency across the 2011 ESC.

Dickinson and Kelly (2011) state that '....it is clear that the methodology for gathering the data does not ensure that adequate information in the nature and quality of the hazardous and non-hazardous materials is obtained'. This statement supports evidence within the 2011 ESC that there are potentially significant knowledge gaps in the non-radiological forward inventory, such as for certain organics, polymers and inorganics, which are described as 'unknown'. We note that past disposal forms did not require comprehensive non-radiological information to be provided.

Arguably, information comprehensive enough to derive the non-radiological component of the forward inventory in sufficient detail is not at present available in the UKRWI and consignors' records, taken together. An example of this is the lack of adequate information on the type and quantity of complexants to meet the requirements of the ESC (we address this issue further in ESC-FI-009).

We will encourage LLW Repository Ltd to make sure that appropriate information is collated as part of the UKRWI for future disposals and will expect the company to engage with both consignors and the NDA to ensure that the relevant data are captured. We expect such effort to be focused on those components of waste disposals that are significant to the ESC. We also note that the effect of the 2010 UKRWI on the non-radiological forward inventory has not been assessed. We recommend that LLW Repository Ltd should engage with the NDA to ensure that future updates of the UKRWI better address the non-radiological components to support future non-radiological assessments within the ESC (**Recommendation INF12**).

The 2011 ESC does not contain a systematic treatment of uncertainty in the non-radiological forward inventory, nor a systematic assessment of variant non-radiological inventory cases. We expect LLW Repository Ltd to consider investigation of the effects of uncertainty and variant cases on the ESC in future updates (**Recommendation INF13**).

LLW Repository Ltd has recognised the need for the collection of improved non-radiological forward inventory information and has implemented revised waste acceptance criteria (WAC) and waste acceptance procedures that require the waste producer to characterise the non-radiological composition of the waste to be consigned. Information derived from the WAC and waste acceptance forms will be used to control the non-radiological waste capacity, with the company proposing to use leachability tests where the non-radiological WAC could be challenged. We believe the collection of further information will provide a greatly improved understanding of the non-radiological inventory in the future, sufficient to support the ESC.

In summary, and as recognised by LLW Repository Ltd, we consider that an improved non-radiological inventory is important for developing the 2011 ESC, in terms of understanding the effects of the non-radiological components of the disposals and the risks they present. Improving non-radiological information will support updates to the non-radiological hydrogeological risk assessment, against which we required improvements (ESC-FI-006).

### **2.2.5. Low level waste tracking system**

The LLWTS is central to collating information on the inventory disposed of to the LLWR and to locating waste containers in the facility. As part of an audit carried out in July 2012, we undertook a sampling exercise to evaluate how LLW Repository Ltd was using the LLWTS (Environment

Agency 2012a). This exercise focused on ensuring that the company could track consignments and that the database could provide specific information on biodegradable organic components in the inventory.

Our audit identified that although LLW Repository Ltd had adequate procedures in place to manage and document the movement of container placements, no auditing had been carried out of the match between actual container placements and those recorded within the LLWTS. We recommend that LLW Repository Ltd should undertake regular audits on a rolling basis to make sure that the LLWTS provides a true representation of the disposals, including the specific locations of consignments in the vaults (see Recommendation INF3).

Subsequent to our audit in July 2012 and in line with our recommendation, LLW Repository Ltd undertook an audit of the LLWTS and container positions. The location of all audited containers was as documented in the LLWTS. This gives us confidence in LLW Repository Ltd's operating procedures.

Our audit also gave us confidence that the LLWTS can be adequately interrogated to provide information on the percentage of organics in a waste consignment. However, we noted that a column within the LLWTS labelled 'other' and used to encompass all other components of a consignment not specifically identified in the LLWTS, appeared to be over-used in some cases. For example, we found that several consignments recorded during 2012 consisted entirely of 'other' materials. Within the LLWTS it was not clear what this 'other' column included in terms of material composition and properties, although LLW Repository Ltd identified that this 'other' information can be retrieved from the records of individual disposals, if required. We recommend that LLW Repository Ltd should adopt a systematic approach to defining 'other' components in the LLWTS. This is particularly important where these components may have environmental safety implications (**Recommendation INF14**).

Within IRF ESC-TQ-INF-005, we queried LLW Repository Ltd's understanding of certain Ministry of Defence (MoD) waste disposed of in Vault 8. Our particular focus was on Ra-226 contaminated waste that are significant to the 2011 ESC as they are important in both the human intrusion and coastal erosion risk pathways. LLW Repository Ltd's initial response did not fully address our queries and so we raised a second IRF (ESC-TQ-INF-005A) to require a more comprehensive response, based on further interrogation of the LLWTS. The second response met our expectations and demonstrated an adequate understanding of the relevant information. However, we note that in providing this information for these 2 IRFs it was apparent that the LLWTS was not easily interrogated for certain waste types and sources. This is a potential area for improvement and we expect LLW Repository Ltd to continue to develop the capabilities of its waste tracking/database systems to facilitate improved information management and accessibility (ESC-FI-020).

We note that the LLWTS can be used as a source of information to produce waste location/distribution maps. We consider that this is potentially of value in some circumstances, to support assessments and management of waste, for example to support and present information on waste emplacement strategies and distribution of container voidage. ESC-FI-010 requests further consideration of how waste information could be used and presented in future ESCs and to support assessments where beneficial.

In the 2011 ESC, LLW Repository Ltd states that it has previously implemented an emplacement strategy for 'reworked containers' that could not be processed through WAMAC to be 'typically repositioned at the top of the container stacks, in order to minimise their load bearing requirements' (LLW Repository Ltd 2011c). We queried whether this had been successfully implemented in IRF ESC-TQ-INF-032. In its response the company states that 95% of the containers are located in positions 4 and 5 of the stacks. This means that 5% of the containers are not located in top-of-stack locations. Thus the existing emplacement strategy has not been fully implemented. However, LLW Repository Ltd has also provided evidence that this will have limited implications regarding voidage and therefore on stack and cap settlement. We accept this conclusion.

We consider that a robust waste tracking system is important to the safe and effective management of past and future waste disposals at the LLWR. A waste tracking system should aid in the implementation of emplacement strategies, allow good access to and presentation of data

and act as a long-term repository of information. We consider that the current LLWTS is no longer capable of meeting all of these expectations and should be replaced or updated. We are aware that LLW Repository Ltd has already recognised this and a programme of work is underway to update the waste tracking system to meet current and future needs. Within ESC-FI-020 we ask for LLW Repository Ltd's plans for the development of a new fit-for-purpose and flexible LLWTS which meets the needs of the current ESC, WAC and permit, including the management of past waste, with the aim of ensuring the effective and transparent management of the entire LLWR inventory of radioactive waste. In the meantime, before the implementation of any new system, we will seek assurances that waste tracking and emplacement strategies are effectively managed utilising appropriate procedures and tools.

## 2.3. Near field

Our review of the near field has covered the following:

- the Level 2 near field report
- 3 Level 3 near field reports
- plus further reports requested from LLW Repository Ltd

Understanding the evolution of the near field is an important component of the 2011 ESC, as it provides an understanding of both radiological and non-radiological releases from the facility. It is also important to have a good understanding of the physical evolution of the waste form, so as to inform the repository engineering design.

LLW Repository Ltd's 2011 ESC submission focuses on 2 key topic areas of the near field, namely its physical and biogeochemical evolution.

### 2.3.1. Physical evolution of the near field

In this section we discuss the near field waste form and its interaction with the repository's passive engineered barrier systems. In particular we focus on the ISO freight containers, drainage in Vault 8 and between future vaults, the impact of voidage on cap performance and the performance of the interim cap. In Environment Agency (2015d) we review the optimisation and performance of the 2011 ESC engineering design (LLW Repository Ltd 2011d), which should be read in conjunction with our review in this section.

#### *ISO freight container condition*

Since 1988 radioactive waste has been encapsulated in ISO freight containers and has been disposed of in an engineered vault, Vault 8. Previous practice was to 'tumble tip' waste into trenches and cover with soil. The aim of this change in strategy was to provide enhanced containment and hence increased protection to people and the environment.

The ISO freight container is designed primarily for transport purposes, but it will also provide safety benefits when waste is grouted inside it. It will provide containment of the waste before burial. After coverage by the final cap it will provide containment and isolation and will slow down the settlement of the waste.

In 2004 the corrosion rate of the ISO freight containers in Vault 8 was measured to be  $0.08 \text{ mm y}^{-1}$  (Coates 2011). The maximum measured rate presented in the 2011 ESC was  $0.78 \text{ mm y}^{-1}$ , which is significantly higher (LLW Repository Ltd 2011b). We questioned this higher rate and LLW Repository Ltd stated that the values quoted by Coates (2011) were not part of the elicited data set. As part of the future ESC work program we expect LLW Repository Ltd to assess any effect of changes in the corrosion rate of the containers on the elicited data used within the 2011 ESC.

Coates (2011) predicted that corrosion at the rate of  $0.08 \text{ mm y}^{-1}$  would likely lead to penetrative corrosion of the lids and walls of the containers by 2011 and 2015 respectively for type 2032<sup>4</sup>

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<sup>4</sup> Type 2032 containers are a variation of the standard ISO freight container design.

containers. The maximum exposure time of containers in Vault 8 was 23 years at the time of the 2011 ESC submission.

As part of our review we carried out an inspection of containers in the north-west corner of Vault 8, to assess whether penetrative corrosion of the lids and walls of the containers had happened. We also wanted to assess whether the 2011 ESC representation of the containers in Vault 8 was realistic (Environment Agency 2015j).

Our inspection identified that corrosion had produced through penetration in a number of containers, especially the older containers in Vault 8. Through penetration of containers by corrosion did not seem widespread in Vault 8, but our inspection assessed only those containers at the top of a stack. It was not possible to assess the condition of containers lower down the stack, as access to these was restricted. However, we note that due to protection provided by the upper containers, we might expect the condition of lower containers to be better than those exposed at the top of stacks, although we note that there is currently no direct evidence of this.

In addition to investigating the nature and extent of container corrosion, we also recorded the wider condition of the containers and the state of any exposed waste and the condition of the grout (see Environment Agency 2015j). We noted:

- vegetation was protruding from the sides and tops of a number of containers, but predominantly from the grout ports, ranging from mosses to bush-like vegetation
- softening of the grout was observed in a small number of containers
- the side walls of some of the full height ISO freight containers were bowed, although it was not clear whether this had happened during emplacement operations, or had developed during storage in the vault
- the extent of ullage evident at the top of containers was significant throughout the north-west corner of the vault
- a significant quantity of water resided on the container lids and in the voidage at the top of containers
- the capping grout on top of the container lids was fragmented in many cases
- the lid drainage holes on top of the containers were sealed in many cases, thus preventing the escape of water
- the container grout port holes had been left open during the storage period in Vault 8, allowing water to enter the containers

Our findings were similarly reflected within LLW Repository Ltd's own, more extensive, container investigation programme (Jefferies 2012).

We queried the implications of these and LLW Repository Ltd's inspection observations for the evolution of the near field and the behaviour of the capping system, for example the proposed engineered cap (see ESC-RI-INF-005). We questioned whether the approach to waste storage and disposal in Vault 8 represented the BAT and posed a number of challenges to LLW Repository Ltd and sought assurances on some issues, as follows:

- Whether higher stacking in Vault 8, as planned, could be implemented.
- We sought assurances that in future ISO freight containers will not be left exposed for periods that might lead to unacceptable container degradation or enhanced discharges.
- The presence of soft grout in the ISO freight containers could affect the chemical and physical behaviour of the waste. We sought evidence from LLW Repository Ltd that the softening of the grout is not extensive across Vault 8. We also requested that LLW Repository Ltd establishes the primary cause of grout softening.
- We questioned how widespread and how significant the voidage is at the top of containers within Vault 8 and what LLW Repository Ltd's understanding is of the effect this voidage could have on the performance of the engineered cap.

- We sought evidence that the growth of vegetation on or in the containers will not affect the performance of the grout. We required that LLW Repository Ltd assesses how this growth can be inhibited in future and current growth safely removed.
- We questioned the presence of water accumulating on the container lids and the impacts this may have on waste and container degradation and ultimately on radionuclide migration to the wider environment (for example via leaching).
- We questioned whether the fragmented grout on top of containers could lead to an increased risk of the drainage network in Vault 8 becoming blocked.

We required LLW Repository Ltd to consider each of these challenges, alongside wider development of an optimised disposal system and to consider how it would develop programmes of work to achieve a fully optimised design in the future, through applying BAT.

To address our questions and its own findings regarding container condition, LLW Repository Ltd established a work programme (Jefferies 2012 and 2013, Shaw 2013). This programme included further container inspections as well as assessment and consideration of necessary engineering steps to address container condition before final capping. We are satisfied with the scope and approach of the work proposed, which is ongoing at the time of writing. We will continue to liaise with LLW Repository Ltd to ensure that this programme meets our requirements. Below we discuss some of the key elements of this programme further.

The current main container design includes a grout port used to infill the container. In the past a decision was taken by the operators not to replace the grout port cover after grout injection. This decision has led to some water ingress into the waste and softening of some grout towards the top of containers. LLW Repository Ltd has established that the softening of the grout is not widespread within individual grouted containers across Vault 8 (Environment Agency 2015j and Westlakes Engineering 2012a and b). The company concluded that weathering is the likely mechanism for the softening and it is unlikely that interaction with a specific waste type has contributed to this phenomenon. To maintain awareness of those containers with observed softening, LLW Repository Ltd proposes to monitor a number of packages to assess whether further softening of the grout is happening. We accept these findings.

From the data presented we concluded that the grout softening is not a significant environmental safety concern. However, keeping the grout port open after filling with grout may not represent BAT and we expect LLW Repository Ltd to address this within its forward programme of work and also to consider any remedial action necessary in the shorter term. We are satisfied with the programme of work the company has presented to address these issues, but have detailed our expectations for the protection of waste before capping within ESC-FI-025. We will expect consideration of the closure of the grout ports after grout injection and wider container optimisation in line with the planned period during which containers will remain exposed, so as to minimise discharges and unacceptable degradation of the containers and their contents. In the shorter term we expect LLW Repository Ltd to consider and implement any immediate actions that are necessary to protect past disposals, for example by 'topping-up' the grout in containers where considered beneficial and part of an optimised solution.

Voidage within the ISO freight containers, in excess of that specified in operational procedures was found to be extensive across accessible containers in Vault 8. A total of 250 containers were inspected, with the majority being type 2032 (Jefferies 2012). The maximum ullage depth at the top of containers (depth to the top of the hardened grout) was 320 mm for a type 2032 container, with the largest average depth being 109 mm for type 2895 containers. In terms of volume, the maximum ullage observed during the inspection was 4.6 m<sup>3</sup> (33%) for type 2032, and the largest mean average was 1.5 m<sup>3</sup> (11%) for type 2895 containers.

The exact cause of the ullage is not at present clear. However, LLW Repository Ltd suggests that the most likely mechanism is settlement of the waste and grout following grouting, under its own weight, into inaccessible voidage not filled with grout during the grouting process. This settlement is thought to generally happen shortly after grouting. To address this issue LLW Repository Ltd has changed its grouting procedures to allow for settlement, before topping up the containers further with grout if necessary. Initial evidence suggests that this approach has been successful in significantly reducing voidage at the top of containers following grouting. The effect of ullage and

voidage more generally on the performance of the capping system is discussed in the Engineering Section of this report and in our review of Optimisation and Engineering (Environment Agency 2015d).

Although there is no specific evidence that vegetation growth on and in containers is detrimental, it is unsightly and may have an impact on waste form integrity. LLW Repository Ltd has therefore committed to remove as much of the vegetation from Vault 8 containers as practicable and will evaluate how best to control the growth of vegetation in future waste packages (Jefferies 2013).

The accumulation of water on top of the container lids and in the voidage within the containers has led to small quantities of radioactive substances leaching to the wider vault environment. Maximum activity levels measured in samples of standing water from inside the containers were 194 Bq l<sup>-1</sup> for Cs-137 and 23,100 Bq l<sup>-1</sup> for tritium. A maximum activity of 9 Bq l<sup>-1</sup> was calculated for Sr-90 (Jefferies 2012). These levels are not considered to be significant and only contribute a very small percentage to overall site discharges. Nonetheless, we expect LLW Repository Ltd to consider how discharges can be reduced such that they continue to represent BAT. We expect future container design to minimise, as far as possible, discharges of radioactivity and for current disposals to be optimised. Discharges may also be reduced and containers protected by the placement of the final cap, partial placement of cap materials or other means of protection. LLW Repository Ltd has identified further steps that may be possible to further optimise container design, such as the removal of drainage plugs on the top of containers to allow free draining of water and improvements to the placement of grout on top of containers. These and other options will be considered as part of the company's forward programme of work. We further detail our expectations within ESC-FI-025 and will monitor LLW Repository Ltd's progress in addressing this FI and the wider optimisation of containers and vault closure.

In summary, the consideration of the condition of containers within Vault 8 has raised a number of issues. LLW Repository Ltd has carried out further work to understand these issues and as a result has established a forward programme of work that should be able to achieve a fully optimised design, addressing the issues raised. We are satisfied with the investigations the company carried out and the programmes put in place. However, to clarify our expectations we raised a FI, ESC-FI-025. Other FIs address our wider expectations regarding the engineering forward programme (ESC-FI-001 and ESC-FI-027). LLW Repository Ltd has already provided details of much of its engineering forward programme in Shaw (2013), including important regulatory review points, which we will use to ensure the outcomes meet our requirements.

## Engineering

After placement of the final disposals in the vaults, the protection of people and the environment will in part depend on a number of engineered barriers. These barriers are expected to have a design lifetime of several hundred years, but may influence the near field hydrogeology for several thousand years (LLW Repository Ltd 2011b). The main engineered features providing this passive safety are the repository cap, the trench and vault walls and bases, the drainage features and the cut-off wall. Below, we discuss the interaction of the waste mass and engineered barriers, in particular the physical behaviour of the LLWR waste mass and its resulting impact on the integrity of the engineered capping system. In Environment Agency (2015d), we discuss in more detail the optimisation, design and performance of engineered barrier systems.

At present an interim cap covers the waste disposed of in the trenches. The function of this cap is to restrict the flow of water into the waste mass. A cut-off wall has also been constructed along the northern and eastern flanks of the trenches, restricting the release of leachate into the surrounding environment.

In response to Schedule 9 Requirement 7 of the environmental permit, LLW Repository Ltd has assessed the performance of the interim trench cap and cut-off wall annually (for example LLW Repository Ltd (2008) and Serco (2011)). The company sought to quantify the water balance of the trench disposals as a way of measuring the rate of water entry into the waste and therefore the effectiveness of the trench cap. Progress in the improvements to the drainage and monitoring infrastructure were reported in the annual Requirement 7 submission. Serco (2011) identified that the cap performance is not as expected, nor as assumed in the 2011 ESC. The cap's performance

is shown to have been only about 58% effective from 1994-2012, with the rate of water entry to the trenches estimated at 282 mm y<sup>-1</sup>.

The 2011 ESC used a combination of data collected before improvements were made to the trench water balance and elicited performance data to develop a rate of water entry into the waste. The observed and calculated rate of water entry into the trench waste was significantly greater than the 50 mm y<sup>-1</sup> assumed in the 2011 ESC (Baker and Shevelan 2012).

We raised IRF ESC-TQ-INF-018, questioning the implications of these higher flow rates through the cap on relevant exposure pathways. LLW Repository Ltd's response shows that the higher flow rate increases the dose to which potentially exposed groups (PEGs) are exposed for some pathways. The expected present day dose to PEGs ingesting water from a hypothetical well located between the LLWR and the coast associated with these higher infiltration rates is estimated to be 2 µSv y<sup>-1</sup> compared with the 1 x 10<sup>-6</sup> risk guidance level that equates to roughly 20 µSv y<sup>-1</sup> (assuming that the exposure is certain to occur) and is therefore consistent with our requirements. Peak impacts are associated with discharges of tritium. We note that current tritium levels monitored in groundwater are locally higher than the average values estimated in the assessment calculations for the 300 mm y<sup>-1</sup> infiltration case and the 50 mm y<sup>-1</sup> infiltration case. Baker and Shevelan (2012) consider this to be a consequence of the simple model of the source term for tritium within the assessment model that does not capture all of the processes that may result in the retention of tritium within the trenches. We agree with this conclusion.

The increased water flow through the interim cap also enhances the calculated release of non radioactive contaminants from the facility, leading to projected exceedances of LLWR groundwater assessment standards for zinc, chromium, molybdenum, lead and nickel by the end of the period of authorisation. However, this is a conservative assessment. Monitoring of the trench leachate has demonstrated that current levels of these contaminants are indistinguishable from the background levels and thus do not present a risk to human health or the environment.

Due to the water flow identified through the interim trench cap and other information arising from investigations into the integrity of the trench cap membrane, we consider the current state of the interim cap may not represent BAT. LLW Repository Ltd is currently investigating and developing strategies to provide a BAT solution and for the period until the final capping system is constructed. The strategies will need to take account of the outcome of all the information available on trench cap performance, as well as taking account of the sequence, timing and extent of the final capping system. We expect the chosen strategy for management and repair of the existing interim trench capping system to meet BAT requirements for the minimisation of impacts until the interim cap is replaced with the final capping system. In Environment Agency (2015d) we discuss in more detail the interaction of the trench cap BAT strategy with the wider LLWR restoration sequence.

The final engineered cap is an important passive safety feature at the LLWR, during both the period of authorisation and the post-closure period. Its performance will directly affect the rate of flow of water into the waste mass and the subsequent evolution of the near field and therefore discharges. Settlement of the waste may influence the performance of the capping system with the extent of settlement influenced to a large extent by the voidage in waste packages and its distribution across the vaults. Voidage within the waste form can arise through a number of mechanisms: it may be present as inaccessible voidage within the waste, compression voidage, or biodegradation voidage generated through the degradation of organic materials. Additionally, voidage present at the top of containers from the ullage space and through settlement of the grout after injection must be taken account of.

During our review of the 2011 ESC we considered it necessary to seek further information on LLW Repository Ltd's understanding of the extent and distribution of voidage within Vault 8. We sought to better understand the company's strategy for the emplacement of waste in Vault 8 and the stacking of containers to achieve acceptable total voidage within any one stack (ESC-RI-INF-005).

LLW Repository Ltd's response provided us with confidence that it had sufficient understanding of the extent and distribution of voidage in Vault 8. However, we note that significant uncertainty still exists, primarily attributable to the lack of information in the waste records on the physical details of the waste form disposed of. As part of the container investigation work, LLW Repository Ltd

undertook a task to gain a better understanding of the voidage in Vault 8 (Penfold et al. 2013). From this task we note the following points:

- The data used by LLW Repository Ltd for deriving the voidage in Vault 8 are the best currently available.
- The data are subject to significant uncertainty.
- The data indicate that there are areas in Vault 8 where the engineered cap could be affected by settlement in the absence of appropriate mitigation. LLW Repository Ltd proposes to add an extra metre of profiling material to the cap to compensate for this; we will assess the adequacy of this when we see the full proposals for container stacking in Vault 8 along with final cap design.
- Before 2003 no record of the amount of grout added to the containers was collated in the LLWTS. However, we note that LLW Repository Ltd has inferred the quantity of grout added to a package, from the quantity of waste and the density of grout. This highlights a second area of uncertainty associated with the derived voidage.
- To derive the voidage within containers, LLW Repository Ltd assessed a density for the waste materials themselves. LLW Repository Ltd has applied 2 methods for assessing the density, and consequently the mass of waste present in waste packages. This is a third area of uncertainty associated with the derived voidage.
- Penfold et al. (2013) predict that the maximum settlement that a stack undergoes will be 2 to 2.25 m. The differential settlement between adjacent stacks appears to range from 0 to 2.25 m, in most cases being between 0 to 1.5 m. The 2011 ESC identifies a practical maximum differential settlement of 500 mm, which is described as generally desirable on a precautionary basis (Tonks 2011); we will therefore expect LLW Repository Ltd to confirm that the increased predicted settlement identified in Penfold et al. (2013) can be accommodated by the capping system before the construction of the final cap.

Jefferies (2012) completed an exercise to determine both the maximum TPV in each of the 2,661 stacks in Vault 8, and the theoretical maximum stacking that could be permitted at each location. Theoretical maximum stack height is calculated on the assumption that the voidage in the existing stack must not exceed the total TPV criterion for that stack. The results show that 67% of the stacks are predicted to meet the maximum stacking criteria (8 high). Only 4% of stacks are predicted not to meet the WAC for 4-high stacking. We conclude that the degree of higher stacking that can acceptably be achieved within Vault 8 remains unclear and uncertain at this point in time and will need to be determined by further work detailed within LLW Repository Ltd's engineering forward programme (Shaw 2013). Within this programme LLW Repository Ltd proposes to establish whether the proposed engineered cap can accommodate the uncertainty associated with the voidage and the degree of predicted settlement in Vault 8, dependent on the extent of higher stacking. Where uncertainty cannot be removed, we expect the incorporation of appropriate factors of safety in the cap engineering design and stacking height. We expect the programme to address the following issues, amongst others:

- the sufficiency of contingency built into the design of the engineered cap to accommodate the uncertainty in the voidage in Vault 8
- the adequacy of proposed monitoring to determine the behaviour of the engineered cap during the period of authorisation
- the sufficiency of the information being collected from consignors in relation to voidage
- the adequacy of consignor and consignment auditing to confirm that consignors are providing appropriately accurate and complete information on voidage
- the adequacy of tools (for example the LLWTS) and processes that LLW Repository Ltd uses to determine voidage within waste packages reliably
- the demonstration of the safety of the proposed degree of higher stacking within Vault 8

We expect LLW Repository Ltd to address the issues raised above before capping Vault 8. We raised a number of FIs, including ESC-FI-001, ESC-FI-025 and ESC-FI-027 to address our

expectations above. The outcome of these FIs should be a fully justified engineered design and vault emplacement strategy, capable of coping with the level of cap settlement expected.

### 2.3.2. Chemical and biogeochemical evolution

Gaining an understanding of the biogeochemical evolution of the near field is an important requirement of any ESC. The evolution of the near field will be governed by numerous parameters and effects, including; the oxidation states of chemical elements, pH, Eh, solubility, sorption characteristics, release rates from waste forms, microbiology, infiltration of rainfall into the waste mass and the degree of waste saturation. These parameters will dictate the release rates of radionuclides and non-radionuclides from the trenches and vaults, including key radionuclides such as U-234 and 238, Tc-99, C-14, I-131 and Cl-36.

To understand the biogeochemical evolution of the near field, LLW Repository Ltd has made use of experimental data, modelling, expert elicitation and monitoring data. The 2011 ESC presents the company's current understanding of how the near field will evolve for the reference case (when the site is predicted to be affected by coastal erosion within a few hundred to a few thousand years) and for a delayed coastal erosion scenario.

LLW Repository Ltd has not yet developed its proposals for near field monitoring within the vault or container environment. In our review of the 2011 ESC monitoring provision, we raised an FI (ESC-FI-018) which recommended that the near field monitoring capability is further developed with the objective of characterising the chemical and biochemical evolution of the waste and grout.

#### *Modelling of chemical evolution*

LLW Repository Ltd used modelling extensively in the 2011 ESC to gain a greater understanding of the near field. Its primary model, the Generalised Repository Model (GRM), facilitates an understanding of how various parameters affect the evolution of the near field. For example, LLW Repository Ltd used the GRM to assess the partitioning of C-14 in the near field and the influence of parameters such as the rate of cellulose degradation. As reported in the 2011 ESC, Teollisuuden Voima Oy (TVO) undertook blind testing of the GRM against a number of Gas Reaction Experiments (GRE) at VLJ Repository Olkiluoto in Finland, to assess the ability of the model to track the evolution of waste degradation processes in practice (Small et al. 2008). The results of this testing against real experiments provides us with confidence that the GRM has the capability to follow the evolution of C-14 in a saturated system (LLW Repository Ltd 2011b). However, we note that the GRE experiments are fully saturated and thus will not be truly representative of the conditions at the LLWR in the early stages of its evolution. Thus, LLW Repository Ltd may need to assess the ability of the GRM (or other similar models that the company may develop) to track conditions more representative of those at the LLWR. This is addressed further in the C-14 section (Section 2.3.2) in this report.

We also note that, on behalf of LLW Repository Ltd, Small et al. (2009) undertook a study to assess the optimum time step for the GRM, using time steps of 0.01 years and 0.05 years. 0.05 years was found to provide the optimum time step. However, the report states that further adjustment of the time steps may happen as a result of refinement of the model and also to take into account different flow models. We advise that if the GRM model is to be used to support future updates of the ESC, then the recommendations of Small et al. (2009) should be taken into account for future use of the GRM and that, in further refinement of the model, LLW Repository Ltd assesses whether the time step for the GRM is still optimum. If a different model is used in future ESC updates, then LLW Repository Ltd should ensure that applicable findings of Small et al (2009) are reviewed (**Recommendation INF15**).

LLW Repository Ltd used a number of other models to gain an understanding of the near field. These models were PHAST (that has been used to examine the significance of the release of uranium from fluoride residues) (Parkhurst et al. 2004), QPAC along with PHAST (used to model the heterogeneity within the vault waste) (Quintessa 2008) and PHREEQC (used to examine the speciation of chemical components within the near field and to build confidence in the geochemical understanding and solubility limits in the assessment calculations) (Parkhurst and Appelo 1999). These models have all been extensively validated and verified and we consider that they are applicable for use in understanding the evolution of the near field.

We are content that the models used in the 2011 ESC have been extensively validated and verified. Subsequent to the submission of the 2011 ESC, LLW Repository Ltd has adopted a different approach to the assessment of C-14 impacts in which arguments are, to an extent, independent of GRM. Any approach should be able to align with the expected repository C-14 release conditions.

## pH

The pH in the trenches and vaults will directly influence the solubility of the key radioactive and non-radioactive substances in the near field. The pH will also play a major role in the evolution of the microbiological environment in the trenches and vaults and the subsequent release of radionuclides via the gas pathway.

The current pH in the trenches is typically 6 to 7 and is primarily governed by the degradation of cellulose and the buffering capacity of the cover soils placed with the waste. The pH in the vaults, however, will be significantly higher due to the large volumes of grout disposed of to the vaults and will typically be between 10 and 11. Within the vaults, there will be localised areas where the pH will be significantly lower than 10 to 11; for example, in the centre of waste pucks from the Waste Monitoring and Compaction Plant (WAMAC). These localised areas are not expected, however, to affect the overall pH of the vaults and the leachate exiting the vaults.

In the 2002 PCSC, BNFL Ltd presented a case where hyperalkaline conditions were assumed in the vaults for about 10,000 years (Environment Agency 2010). However, the reference case in the 2011 ESC assumes that coastal erosion of the site will commence in a few 100 to a few 1000 years with subsequent complete destruction taking a few 1000 years after the initial breach of the site, so that hyperalkaline conditions existing for such a long period are no longer likely to be relevant.

Using a series of variant cases in the GRM, LLW Repository Ltd demonstrated that reducing the quantity of grout in the vaults would not significantly affect the evolution of the vault pH (Small et al. 2011a). The only exception was a case where the grout content was zero and in this case low pH conditions of 6 to 7 prevailed for the first few hundred years of the simulation. The GRM variant cases provided confidence that the high pH conditions in the vaults are likely to be maintained until the facility is subject to disruption by coastal erosion. In ESC-FI-028 we asked LLW Repository Ltd to develop further the conceptualisation of the eroding waste mass. We would expect the outputs of this FI to inform the future development of near field models during the repository erosion sequence.

We note that, in the extreme variant case of zero grout, the high pH maintained in the later stages is achieved by a secondary buffering effect, resulting from the corrosion of metal waste. In the future, however, the quantity of metals that will be disposed to the LLWR is likely to be reduced as a result of diversion of the metals away from the LLWR following implementation of the national nuclear LLW strategy. This in turn could reduce the secondary buffering effect. We also note that LLW Repository Ltd may in future alter its practices and dispose of packages containing less grout. Both these factors could influence the hyperalkaline conditions produced in the vaults. We will expect the company to continue to assess the impact of waste composition changes, particularly at annual and major reviews of the ESC.

Specifically, we will expect LLW Repository Ltd to put processes in place to monitor and respond to any effects of near field composition changes. We will also expect the company to maintain awareness of the implications of possible changes in waste composition resulting from developing radioactive waste treatment processes or alternative disposal options. We outline our expectations in this area within FI ESC-FI-014.

Within FI ESC-FI-018 we note that the 2011 ESC does not identify experiments or monitoring to be carried out to improve understanding of the chemical evolution of the near field after placement of the final cap. As part of the development of a forward work programme we expect LLW Repository Ltd to consider the need for such monitoring or experiments.

We also expect LLW Repository Ltd to continue to monitor the pH of the leachate from the trenches and the vaults to validate the 2011 ESC conclusions.

## Colloids

In our review of the 2002 PCSC and Requirement 2 submission, we highlighted our views about colloids and their potential to enhance the mobility of radionuclides from the near field into the geosphere (IAF NRF\_010.1 and IAF NRF\_010.2).

LLW Repository Ltd has previously characterised the type and numbers of colloids present in the near field and geosphere at the LLWR. In the trenches, iron and silicon colloids are the principal species present and have been found at densities of  $10^{14}$  particles per  $m^3$  (Trivedi et al. 2008). These colloids have been shown to have alpha radionuclides adsorbed onto their surfaces, but none of these colloids have been detected in the geosphere. This would appear to indicate that colloids in the near field become unstable when traversing from the trench near field to the geosphere. LLW Repository Ltd has demonstrated experimentally that this is likely to be the case, but we note that these experiments used relatively extreme conditions.

LLW Repository Ltd has also shown that the transfer of radionuclides by organic-based macromolecules from the near field of the trenches to the geosphere is unlikely (Trivedi et al. 2008). The leachate originating from the vaults has never been analysed for colloids, but LLW Repository Ltd has indicated that grout-based colloids, which might be expected within the vaults, are not likely to be stable<sup>5</sup>. We agree.

In our review of the 2002 PCSC, we recommended that BNFL Ltd (the then permit holder for the LLWR) undertook a sensitivity case to assess the effect of colloids on the groundwater pathway (IAF NRF\_010.1). LLW Repository Ltd has completed a very cautious variant case examining the effect of zero retardation in the near field on the groundwater pathway assessment (Kelly et al. 2011), which cautiously bounds the potential effect of colloids as their presence would not imply zero retardation. Resultant risks just exceeded the GRA risk guidance level, but we note that this is an extreme and very cautious case, unlikely to happen in practice.

We also note that, for this extreme case, LLW Repository Ltd has demonstrated, using the GRM, that the risks associated with the presence of colloids are not significantly increased from those of the base case (Trivedi et al. 2008).

The work completed within the 2011 ESC by LLW Repository Ltd has provided us with confidence that colloids are unlikely to present a significant risk via the groundwater pathway. However, the points made earlier raise questions about the conclusions reached and whether more work could be done to confirm these conclusions. We note that in IAF NRF\_010.1 we had previously requested that the company undertakes further R&D on colloids. This request was not taken forward (Environment Agency 2010). This decision was based on the outputs of a sensitivity analysis LLW Repository Ltd completed to assess the effect of colloid 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 near field environment the risk guidance level would only just be exceeded. LLW Repository Ltd considers that this is an extreme case and we agree.

Despite this conclusion, we note that there are a number of national and international R&D programmes under way that could provide further information on the behaviour of colloids in near-surface disposal facilities and geological disposal systems, for example the Radioactive Waste Management Ltd. Science and Technology Plan (NDA 2014). We shall expect LLW Repository Ltd to maintain an awareness of these programmes and to apply any relevant learning to the LLWR.

Within the 2011 ESC, LLW Repository Ltd has not identified any further experimental or monitoring work on colloids. We consider that it is good practice not only to model the potential impact of colloids, but also to establish a proportionate programme of monitoring to confirm the conclusions reached within the 2011 ESC. We consider this monitoring important as near field conditions may evolve significantly over time, potentially affecting the number and types of colloids and their

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<sup>5</sup> We note that because a representative vault leachate is not likely to be generated for an extended period, it is not currently viable to characterise the vault leachates for colloids.

behaviour across the near field-geosphere boundary. We detailed our expectations within FI ESC-FI-015.

### Complexants

Complexants present in the near field may facilitate the transport and increase the solubility of radionuclides and non-radionuclides. Typical complexants that may be present in the LLWR near field are superplasticisers, isosaccharinic acid, aminopolycarboxylic acids, polycarboxylic acids and Tributyl Phosphate (TBP). The presence of these species may increase the risk associated with the groundwater pathway (LLW Repository Ltd 2011b).

Superplasticisers are added to the grout at LLWR to increase its fluidity, allowing improved penetration into the containerised waste. Sikament-10 has been used, but due to the manufacturer ending production, LLW Repository Ltd has replaced it with Sikament-700 (Cummings 2014). It has been reported that superplasticisers can potentially facilitate the transport of radionuclides from the near field to the geosphere. Our review of the 2008 Schedule 9 Requirement 2 response to the permit (Environment Agency 2009) sought clarification and evidence that Sikament-10 would not promote the release of radionuclides from the LLWR (see also in IAF NRF\_012.1). We recommended that BNFL Ltd (the then permit holder for the LLWR) should undertake a sensitivity test to assess the effects of superplasticisers (Galsons Sciences Ltd and Environment Agency 2004).

To address our concerns, LLW Repository Ltd commissioned a desk-based study to assess the effect of superplasticisers. The company concluded that the effect on the groundwater pathway from the presence of superplasticisers in the near field is minimal. This is due to the slow diffusion rate of superplasticisers from the grout matrix, which will limit their concentration in pore water and thus their ability to form complexes with radionuclides (Trivedi et al. 2008). We accept that this is likely to be so, but note that the data were obtained from trials carried out on freshly grouted coupons and so we recommend that any future experiments are also carried out on aged coupons.

We note that, in addition to the desk-based study, LLW Repository Ltd has assessed the effect of complexation by way of a variant case for the groundwater pathway (Kelly et al. 2011). This examines the effect of reduced retardation in the near field and demonstrates that the GRA risk guidance level would only just be exceeded, even for an extreme case. We accept that this scenario is unlikely to happen. In IRF ESC-TQ-INF-026 (see also NRF\_010.2) we also asked LLW Repository Ltd to assess the effects on uranium of combined high solubility and no adsorption. In response, LLW Repository Ltd presented a combined variant case which demonstrated acceptable risks.

The evidence presented in the 2011 ESC gives us confidence that the effect of Sikament-10 on the release of contaminants from the near field will be minimal. We expect LLW Repository Ltd to demonstrate that a new superplasticiser, such as Sikament-700, will also have minimal effect on the release of contaminants from the near field. We recommend that LLW Repository Ltd should assess the leachability of Sikament-700 from both fresh and aged samples of grout; this work could be carried out as part of wider investigations into the leachability of the LLWR grout formulation (**Recommendation INF16**).

At the time of writing this report, complexants are not permitted to be disposed of at the LLWR by the environmental permit, although this has not always been the case, with the potential for disposals to the trenches prior to the implementation of the current permit condition.

We note that these materials can, in some cases, enhance the solubility of important radionuclides. For example thorium (Th) can be affected at pH <8 and species such as nickel (Ni) and technetium (Tc) can potentially have their solubility increased by a factor of 2. We also note the specific statements made about ethylene diamine tetra-acetic acid (EDTA) (Randall et al. 2011):

- 'EDTA and citrate had the biggest impact on thorium solubility ...'
- 'EDTA can potentially give significant solubility enhancements at pH 8 for nickel and thorium as well as technetium and plutonium under reducing conditions....'

- 'EDTA has a significant effect on thorium behaviour.... At pH 11,  $1 \times 10^{-3}$  M EDTA increases the thorium solubility by over two orders of magnitude. At pH 7, just  $1 \times 10^{-5}$  M increases the solubility by over four orders of magnitude'

As part of the permit variation application (LLW Repository Ltd 2013c) LLW Repository Ltd has proposed to modify the LLWR environmental permit (and WAC) so that certain complexants can routinely be accepted for disposal. In substantiating this change, the company has assessed the effects of complexants on the risks associated with groundwater pathways. In Kelly (2013a), the company concludes that the presence of EDTA in the near field will have only limited effect on the release of radionuclides. For a reference concentration of  $10^{-7}$  mol dm<sup>-3</sup> for the trenches and a loading for the vaults of  $6 \times 10^{-6}$  mol dm<sup>-3</sup>, the risk associated with the groundwater well and stream pathways for the RDA and the EDA will only be slightly increased and will not exceed the risk guidance level. We accept this assessment.

LLW Repository Ltd also concluded that most complexants that might be disposed of in the LLWR will have little effect on the risk associated with the groundwater well, stream and marine pathways, because they will be biodegraded within the near field environment. Thus LLW Repository Ltd is proposing that controls on most complexants are removed, unless bulk quantities are disposed; where a limit of 1 kg on bulk disposals of any complexant will be applied through the WAC (Taylor and Baker 2013). The only exceptions to this would be aminopolycarboxylic acids such as EDTA, Nitritotriacetic acid (NTA) and diethylene triamine penta-acetic acid (DTPA). The company has concluded that these complexants can have a significant effect on the solubility and sorption of radionuclides and non-radioactive substances in the near field and are known to be more resistant to biodegradation and hence more persistent in the near field and wider environment. LLW Repository Ltd proposes to limit the disposal of these materials to a 1500 kg total capacity for the EDA. It will also apply the 1 kg limit for bulk disposals of all complexants. We accept this assessment and the proposals.

Lead (Pb) is an important non-radiological substance that is strongly bound by EDTA and this has influenced the Pb capacity of the LLWR. Using a highly cautious model, LLW Repository Ltd initially concluded that the facility could not accept the Pb inventory proposed in the inventory reference case (Case A in the 2011 ESC). Changes were made to the model to remove a number of conservatisms and to produce a more realistic, but still cautious model. These were (Taylor and Baker 2013):

- the assumed corrosion rate of Pb was reduced from 20 microns per year to 1 micron per year
- a declining value was used for the EDTA concentration in the trenches, compared with that of the cautious model, where the EDTA concentrations remained constant over whole period of the simulation
- an assumed thickness of 2 mm was used for the Pb disposals (compared with 5 mm in previous assessments) to the LLWR

The resultant cautious, but more realistic model, demonstrates that the reference case inventory of Pb can be accepted at the LLWR. The peak average groundwater concentration of Pb between the coast and the facility is calculated to be  $0.0037$  mg l<sup>-1</sup>, which is below the Drinking Water Standard of  $0.01$  mg l<sup>-1</sup> (Taylor and Baker 2013). LLW Repository Ltd has also assessed several variant cases that provide us with further confidence that the drinking water standard is unlikely to be exceeded at this location.

The work carried out by LLW Repository Ltd supports the conclusions that, with the proposed limit for EDTA of 1 kg per waste package for bulk disposals and a capacity limit of 1000 kg for the RDA (or 1500 kg for the EDA): (1) the presence of EDTA will not lead to the risk associated with the groundwater pathway exceeding the risk guidance level; and (2) the presence of EDTA will not affect the reference case inventory for the LLWR. We accept that both conclusions are reasonable, but we recommend that LLW Repository Ltd addresses the following issues to provide us with further confidence that they are valid (see ESC-FI-009):

- Further sampling for EDTA in the trench leachate. We note that only 5 samples were taken to establish the reference concentration of EDTA for the trenches and seek further confidence that the concentration found is truly representative of the trench leachate<sup>6</sup>.
- Further engagement with Sellafield Ltd and other consignors, to make sure that the reference concentration of EDTA calculated for disposals remains representative. Allowing the disposal of complexants to the LLWR could potentially alter practices at the sites and could lead to an increase in the use or disposal of complexants, especially during further decommissioning work. We expect LLW Repository Ltd to carry out periodic checks that the EDTA reference concentration chosen in the assessment remains valid in future.

We also recommend that if bulk quantities of complexant are disposed of to the LLWR an assessment of the possible effects of heterogeneity in the vaults should be completed. This could assess, in particular, whether the placement of bulk quantities of complexant next to disposals containing high quantities of strongly complexed pollutants (for example lead) could affect the results of the 2011 ESC assessments (**Recommendation INF17**).

We also note that LLW Repository Ltd states that EDTA is considered the most suitable representative aminopolycarboxylic acid because '...it is by far the most commonly used example of this type of complexant in commercial preparations of decontamination agents in use in the UK, which are the source of the material in waste (diethylene triamine penta-acetic acid (DTPA) has not been identified in such preparations and NTA is only present in much smaller quantities than EDTA)' (Taylor and Baker 2013).

We consider it unlikely that DTPA has been disposed of to the LLWR. However, the records of disposals to the trenches contain very little information on the presence of complexants. We note that the complexant effects of DTPA are greater than those of EDTA. We recommend that periodic sampling and analysis for DTPA in the trench leachate is carried out to confirm that the conclusion reached in Taylor and Baker (2013) remains valid (**Recommendation INF18**).

We also note that there is the potential for other complexants to be present in future disposals to the LLWR. LLW Repository Ltd should maintain an awareness of this possibility, to make sure that no other complexants need to be considered in the ESC. Along with continued dialogue with consignors, we will expect consideration of periodic sampling and analysis of leachate to identify the presence of any other complexants present (see ESC-FI-009).

Berry et al. (2013) provide the supporting information for deriving the non-radiological component of the inventory. The report provides solubility and sorption data for non-radiological species for the vaults and trenches in the presence of EDTA. We support LLW Repository Ltd's use of these data, but note that in some cases the explanation of why particular values were chosen is very limited. For example, the Kd for tri butyl phosphate chosen for the soil and grout is  $1 \times 10^{-4} \text{ m}^3 \text{ kg}^{-1}$ . The explanation for this choice is that 'No appropriate references were found in the databases for soils or cements. A Kd value of  $1 \times 10^{-4} \text{ m}^3 \text{ kg}^{-1}$  for both soil and grout is suggested, the same value as that for benzene'. We seek more detailed substantiation in future ESC submissions as to why particular values for sorption and solubility data have been chosen. If no relevant data are available, LLW Repository Ltd should consider undertaking experimental work to provide the data (**Recommendation INF19**).

In summary we are confident that LLW Repository Ltd has carried out a robust assessment of the nature and consequences of potential disposals of complexants to the LLWR, demonstrating an understanding of likely disposals and their consequences on impact pathways. When controlled by the proposed WAC, impacts have been demonstrated to remain consistent with our requirements. We conclude that its proposals for the disposal of complexants are acceptable and can be effectively controlled. We have, however, made several recommendations to ensure that LLW Repository Ltd continues to regularly review and assess this area of work, for example using operational feedback, consignor information and monitoring.

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<sup>6</sup> In our review of 2011 ESC monitoring provision we recommend that sampling of trench leachate and groundwater is undertaken to characterise complexants disposed of in the trenches.

## *Heterogeneity*

The distribution of waste in the vaults and the trenches is important, as it will play a key role in the biogeochemical evolution of the near field. LLW Repository Ltd has presented qualitatively its understanding of the heterogeneity across the LLWR, in particular focusing on the 4 major waste forms accepted for disposal (Small et al. 2011b). Heterogeneity is addressed quantitatively through the GRM.

A variant GRM case has assessed the effect in the near field of waste heterogeneity in Vault 8 on the release of acetate and uranium and also pH and Eh (Small et al. 2011a). The changes to the outputs from the GRM observed in the variant case are small and thus heterogeneity of the waste in Vault 8 does not appear to have a significant effect. However, we note that Vault 8 is not completely full and that further assessment will be required in future to make sure that the full effects of heterogeneity in Vault 8 are understood. We support LLW Repository Ltd's progress in using the GRM to assess the effects of heterogeneity and recommend that it continues to model this for the vaults.

We note that that the degree of discretisation of the GRM is far greater for the 2011 ESC than that presented for the 2002 PCSC. However, LLW Repository Ltd has not explored the sensitivity of the GRM outputs to the degree of discretisation of the model. Irrespective of the future usage of the GRM model, we raised ESC-FI-016 to ensure that this matter is addressed in future updates of the ESC.

## *Grout heterogeneity*

The Level 2 near field report states that the average grout content of ISO freight containers disposed to the LLWR is approximately 60% or greater (LLW Repository Ltd 2011b) for those consignments from WAMAC and 40% for direct consignments (Small et al. 2011b). Small et al. (2011b) indicates that a significant number of direct consignments to the LLWR have grout contents that deviate significantly from the average 40%. Approximately 2500 containers have grout content below the 40% average and in some cases it is as low as 10%. In IRF ESC-TQ-INF-006 we questioned the effect of these containers on the evolution of the near field and the potential settlement of the engineered cap.

In response to IRF ESC-TQ-INF-006 and under the container issues programme (Jefferies 2012 and 2013), LLW Repository Ltd has adequately addressed our questions and recognised the potential role of low grout content waste packages on the nature and extent of waste settlement. As part of the engineering design justification process, LLW Repository Ltd will seek to develop an engineered cap design capable of withstanding the nature and extent of container settlement. We are confident that this can be done. However, we note that low grout content is only one variable property of waste packages that the engineered cap will have to accommodate. Other variable properties will need to be addressed to provide us with confidence that the engineered cap is fit for purpose, for example cellulose degradation and voidage content.

We expect future updates of the ESC to include an increased understanding of the impact on near field performance of low grout to waste ratio containers, which were identified during the container condition investigations (**Recommendation INF20**).

## *Effect of cellulose degradation on vault waste settlement*

LLW Repository Ltd used the GRM to model the effect that the degradation of cellulose would have on the settlement of the engineered cap (Small et al. 2011a), as discussed in Section 2.3.1 on engineering. The discretisation of the GRM is such that one square in the model equates to approximately 200 ISO freight containers. In our review of Tonks (2011) we were unsure whether this degree of discretisation of the model is sufficient for LLW Repository Ltd to gain an adequate understanding of the differential cap settlement that may occur. This relates to both the scale of discretisation, as well as the magnitude of uncertainty associated with the quantification of cellulose content used to inform the model.

Irrespective of the outputs of the container condition investigations we did not consider the GRM fully capable of quantifying the nature and extent of vault settlement. As part of its container condition work, LLW Repository Ltd carried out further investigations into the settlement of Vault 8

waste. This investigation presented an assessment of the differential settlement that may occur between adjacent stacks, taking into account all types of voidage (Penfold et al 2013). This work supersedes the settlement assessment using the GRM model presented in the 2011 ESC.

We accept that the distribution and extent of degradation of cellulose waste and its resulting impact on settlement can and should be modelled, but we recommend that future modelling of container settlement incorporates a more realistic degree of discretisation and greater consideration of the geotechnical response of containers to the loss of waste volume resulting from cellulose degradation (**Recommendation INF21**).

## Uranium

In the 2002 PCSC, uranium and its daughters were found to be the major radionuclides contributing to the risk associated with the groundwater pathway tens of thousands of years in the future. In the 2011 ESC, this is not so, because the likelihood is that the site will be disrupted by coastal erosion before significant in-growth of the daughter products from the uranium decay chain. The radionuclides important to the groundwater pathway in the 2011 ESC are Cl-36, I-129 and C-14. Uranium and its daughters only become important in the case of the delayed coastal erosion or no erosion scenarios (LLW Repository Ltd 2012a).

The trenches contain the majority of the uranium disposed of (5.88 TBq U-234 and 6.70 TBq U-238) (LLW Repository Ltd 2011a) and in our assessment of the 2002 PCSC we questioned LLW Repository Ltd's understanding of the release of uranium from these past disposals, that originated primarily from the Springfields site. LLW Repository Ltd completed a substantial experimental programme to gain a better understanding of the characteristics of the leachate from these disposals. We support this work and commend how it has led to a better understanding of the material and the leachate characteristics, but note that even after this work significant uncertainty still remains. However, we are satisfied that LLW Repository Ltd has appropriately taken account of this remaining uncertainty. For example, the company has modelled uranium using what appear to be cautious sorption and solubility coefficients (we challenged this in ESC-TQ-INF-026 and are content with the response). LLW Repository Ltd will also continue to monitor for uranium throughout the period of authorisation and therefore may be able to identify and assess any significant changes to its assumptions.

LLW Repository Ltd undertook an elicitation exercise to establish the solubility and sorption ranges applicable to the modelled trench and vault environments (Jackson et al. 2011). We questioned, via IRF ESC-TQ-INF-026, why the elicited range of values used in the 2011 ESC was narrower than that applied by NIREX for a geological disposal facility (RWMD<sup>7</sup> 2010). We also noted that the 2011 ESC assessed separate variant cases of reduced sorption and increased solubility. We questioned whether this is realistic as it is likely that these 2 parameters will simultaneously affect the release of uranium from the near field and whether a combination of increased solubility and reduced sorption could potentially exceed the risk guidance level of  $1 \times 10^{-6} \text{ y}^{-1}$ .

LLW Repository Ltd's response provided clarification as to why a narrower range had been chosen for the solubility and sorption parameters for uranium in the 2011 ESC (Baker 2013a) compared to that used by NIREX for example. We accept the arguments presented in this response.

In response to our second query, LLW Repository Ltd assessed a range of sorption and solubility variant cases to determine whether any combination will lead to the risk guidance level being exceeded. The risk guidance level is not exceeded in any variant assessed. For example, the case of infinite solubility and zero sorption gives risks from the trenches and vaults of  $8.4 \times 10^{-7} \text{ y}^{-1}$  and  $3.6 \times 10^{-7} \text{ y}^{-1}$  respectively (Baker 2013a). These are lower than the risks from the reference cases in the 2011 ESC. We are therefore content that LLW Repository Ltd has addressed our concerns.

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<sup>7</sup> Radioactive Waste Management Directorate of the NDA, now Radioactive Waste Management Ltd.

## Carbon-14

Most of the C-14 activity disposed of to the LLWR will be in the vaults (24 TBq), with only a small fraction in the trenches (0.098 TBq) (LLW Repository Ltd 2011a). C-14 can be released from the near field, to either groundwater or gas pathways, or can be incorporated into the solid matrix within the near field. C-14 is a key contributor to the risk associated with the well, marine, estuary and gas pathways. For the groundwater pathways (well, marine and estuary), C-14 is primarily eluted in the organic form, for example, acetate, and/or in the inorganic form, for example, bicarbonate. For the gas pathway, C-14 is primarily released from the vaults as methane (CH<sub>4</sub>), whereas from the trenches equal amounts of carbon dioxide (CO<sub>2</sub>) and CH<sub>4</sub> are produced.

In the 2011 ESC, the GRM was used to model the partitioning of C-14 in the near field. Each vault cell in the GRM consists of approximately 200 half height ISO freight containers, covering regions in the order of a linear distance of 10 m. This approach enabled interactions between individual waste containers over a substantial distance to be modelled. The interactions between waste containing C-14 and bulk gas generating waste such as cellulose could therefore be modelled. This modelling showed significant quantities of C-14 being released via the gas pathway.

During the first few hundred years after the engineered cap has been constructed it is likely that the ISO freight containers will remain relatively intact and there will be minimal interaction between the waste in the containers. The conditions in the vaults will be predominantly unsaturated, except for those containers located near the bottom of a stack that may be sitting in leachate. The gas production from each container will depend on the local conditions in that container, for example the presence of biodegradable materials and the saturation state of the wastes. The C-14 released from the lower containers in the stack may be able to interact with waste due to the saturated conditions that are likely to be prevalent in the early stages of development of the vaults, thus allowing waste materials within different containers to interact. This allows C-14 waste to interact with bulk gas generating waste, which may subsequently lead to greater releases of C-14 from the lower containers via the gas phase.

In the 2011 ESC, the risk from C-14 via the gas pathway to a person representative of the group at greatest risk (an individual that obtains all their vegetables, fruit and some animal products from an agricultural smallholding established over the area of the vaults) exceeded the risk guidance level after the end of the period of authorisation at 2180. As LLW Repository Ltd stated that the gas pathway assessment model was overly conservative, we asked it to undertake further 'cautiously realistic' assessment in ESC-RI-ASO-005. Resulting from their 2011 ESC findings the company modified the GRM to develop a more realistic representation of conditions in the vaults and has used it to model the vaults on the container scale, also addressing our request in the IRF. In addition, the company re-assessed its understanding of the speciation of C-14 in a number of the key waste forms likely to be disposed of to the LLWR. LLW Repository Ltd revisited its understanding of the mechanisms by which C-14 is released from C-14 containing waste, for example metals, graphite, ingots and ion exchange resins. The company concludes that the risk associated with C-14 via the gas pathway is reduced from that presented initially in the 2011 ESC (Sumerling 2013a). The risk has been calculated as  $1.8 \times 10^{-7}$  for a self sufficient smallholder, which is below the risk guidance level. We accept this to be the case for the data that are presented.

We commend the work that LLW Repository Ltd has done to improve its understanding of the evolution of the near field and the release of C-14 via the gas pathway. However, we note that further work will be required to continue to improve understanding in this area. The company acknowledges that further work will be required from now, for example 'Work is ongoing in the NDA/RWMD program and in EC projects in which RWMD participates, that could further support or refine the assumptions in this area' (Sumerling 2013a). We expect to see the company apply any improved understanding in future iterations of the ESC and to make use of further experimental work, modelling and engagement with experts, to continue to improve its knowledge in this area.

In the 2011 ESC, LLW Repository Ltd states that the GRM has been validated against a number of international studies. As discussed above in Section 2.3.2, Biogeochemical modelling and relevant experimental work was carried out at Olkiluoto in Finland (Small et al. 2008; LLW Repository Ltd 2011b). These experiments were performed under fully saturated conditions that are not fully

representative of the unsaturated conditions that are expected to prevail at the LLWR during much of the evolution of the near field. In the past, LLW Repository Ltd has commissioned a number of experiments at the LLWR itself to gain a better understanding of the degradation of waste under typical conditions that will prevail in the trenches and the vaults (LLW Repository Ltd 2011b). The Long-term Trench Experiments (LTTE) provided data on the degradation of waste under typical trench conditions, whilst the Long-term Vault Experiments (LTVE) assessed the degradation of waste under conditions relevant to the vaults. The data obtained from the LTTE were used in the 2011 ESC to develop LLW Repository Ltd's understanding of the trenches. However, no similar data were obtained from the LTVE.

We consider that further work would be beneficial to the future development of the ESC addressing the degradation of waste containing C-14 under unsaturated conditions in the vaults and further validation of partitioning modelling within the GRM or alternative near field model. We recommend that LLW Repository Ltd considers further experimental and/or near field monitoring work, similar to the GRE work carried out at Olkiluoto, to support the future near field modelling, particularly in relation to the partitioning of C-14 and the behaviour of C-14 in unsaturated vault conditions (**Recommendation INF22**).

We note that the capping of Vault 8 is likely to begin in the near future. Gas monitoring of Vault 8 would provide further supporting evidence to validate the assessed rate of release of C-14 via the gas pathway. We recommend that LLW Repository Ltd undertakes an appropriate programme of gas monitoring from Vault 8 after the vault has been capped. LLW Repository Ltd should consider use of any data obtained from this monitoring programme to support the modelling carried out in the 2011 ESC (**Recommendation INF23**).

In the updated GRM model supporting the C-14 reassessment, the GRM is spatially discretised to represent a half height ISO freight container in detail. In the model, it was assumed that, 'For a grout thickness of 0.14 m each waste cuboid has dimensions of 0.60 m x 1.01 m x 1.28 m and the total volume of the waste regions is 11.6 m<sup>3</sup>, which is approximately 0.65 of the internal volume of the container (17.8 m<sup>3</sup>)' (Sumerling 2013a). The 0.65 ratio within the container is close to the average estimated for direct consignments to the LLWR. However, in IRF ESC-INF-TQ-006 we highlighted the fact that there are a significant number of containers that have a waste content higher than the above ratio and thus lower grout content. This could potentially affect the interaction between different waste materials within a container and we therefore recommend that LLW Repository Ltd makes sure that extremes of waste to grout ratios within containers are considered and as necessary assessed, in particular in relation to C-14 behaviour (**Recommendation INF24**).

Microbiology will play an important role in the partitioning and release of C-14 from the near field. The 2011 ESC provides evidence supporting the phased development of the microbiology in the trenches but not in the vaults. Methanogenesis is an important stage in the evolution of the near field environment. The onset of methanogenesis is very dependent on temperature, pH, nutrient availability and other parameters in the near field and, if the conditions are not favourable, other anaerobic microbes can outcompete methanogens. The experiments performed at TVO in Finland support the view that methanogenesis can be established in grouted wastefroms. However, the conditions that will prevail at the LLWR in the early stages will be different from those in the TVO experiments. In addition, future waste treatment processes could lead to waste being disposed of to the vaults that are different from those used in the trials at TVO.

We are therefore not certain that methanogenesis will be established in the vaults and, if this is not certain, what the effect would be on the 2011 ESC assessments. We recommend that LLW Repository Ltd considers the use of vault and laboratory based investigations into the nature and extent of microbiological processes in the grouted waste form (**Recommendation INF25**).

We also recommend that LLW Repository Ltd continues to maintain a watching brief as to what materials act as energy sources for microbial metabolism and, in particular, whether substrates such as graphite can act as a nutrient source (**Recommendation INF26**).

## Interaction between exposure pathways

The 2011 ESC indicates that there are a number of pathways through which PEGs can be exposed to radioactive and non-radioactive contaminants. In the 2011 ESC each of these pathways has been assessed separately. However, an event affecting 1 pathway may also affect another. For example, a human intrusion event will not only present a risk to the intruder, but may also alter the environment in the near field and therefore affect the risks associated with the groundwater and gas pathways.

We consider that 2 major events could alter the evolution of the near field, namely human intrusion and coastal erosion.

A human intrusion into the trenches or the vaults is likely to alter the characteristics of the near field; for example, it will probably lead to higher fluxes of water permeating into the waste mass. It may also alter gas production both locally and further from the intrusion event. LLW Repository Ltd has assessed a number of scenarios as part of the human intrusion assessment. These scenarios will each have a different effect on the evolution of the near field and potentially the risks associated with the groundwater and gas pathways. Therefore, we recommend that LLW Repository Ltd should investigate the effect of human intrusion on the evolution of the near field and the consequences for the risks associated with the gas and groundwater pathways. Any additional assumptions needed for this investigation should be simple and plausible, building on the human intrusion scenarios already assumed to have occurred. Variant scenarios need not be explored unless small changes in assumptions could make the longer term outcome radically worse (**Recommendation INF27**).

Coastal erosion is also likely to alter the biogeochemical evolution of the near field and potentially affect the risk associated with the gas and groundwater pathways. For example, depending on the mechanism of coastal erosion, there could be extended periods where access to the waste is created, allowing air and water into the waste before completion of erosion. In ESC-FI-028 we asked LLW Repository Ltd to further consider how coastal erosion may affect exposure pathways.

## Gas

The main radioactive gases released from the LLWR will be tritiated gases, C-14 labelled carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>), and radon (Rn-222) (LLW Repository Ltd 2011b). Tritiated gases will mainly be released during the period of authorisation, whilst C-14 labelled CO<sub>2</sub> and CH<sub>4</sub>, together with Rn-222, will be the predominant radioactive gases released after the period of authorisation. In addition to radioactive gases, non-radioactive gases will also be released, with CH<sub>4</sub>, CO<sub>2</sub> and hydrogen (H<sub>2</sub>) being predominant, together with smaller quantities of hydrogen sulfide (H<sub>2</sub>S), ammonia (NH<sub>3</sub>), nitrogen (N<sub>2</sub>) and a wide range of other trace gases associated with the degradation of waste.

C-14 was discussed in the C-14 section of this report and is not considered further here.

The rate of release of Rn-222 to the environment will depend on the form of the waste and the performance of the engineered cap. The half-life of Rn-222 (3.8 days) is far shorter than that of C-14 (5,730 years) and thus, whereas the activity of C-14 is not significantly reduced before reaching and traversing the cap, Rn-222 activity is substantially reduced by radioactive decay as it may take a number of half lives to escape the engineered barriers. The clay layer and the gas collection layer provided in the cap are important barriers to the release of Rn-222. We queried via IRF ESC-TQ-INF-035 what the effect on the risk from the gas pathway would be if the engineered cap did not perform as designed. In particular, we were concerned about the effect of localised cracking of the clay layer on the release of Rn-222 to the environment. In response, LLW Repository Ltd provided us with confidence that such cracking is unlikely and will not present any further risk to the PEGs presumed to be located on the cap (Sumerling 2013b). This paper also justified the choice of emanation factor applied to the vault and trench waste used in the 2011 ESC. We are content with the company's response. As part of the development of the engineered cap design, we will expect the mitigation of Rn-222 release via the cap gas drainage design to be taken into account. Overall, we are content that LLW Repository Ltd's assessment of the Rn-222 gas pathway is cautious.

As stated earlier, a wide range of non-radioactive gases will be released from the LLWR, the main ones being CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub> and H<sub>2</sub>. We are satisfied with LLW Repository Ltd's assessment that these gases do not present an unacceptable risk due to the relatively low volumes produced at the LLWR. However, the rate at which these gases are released from the facility is not provided in the 2011 ESC. This information is important for understanding the flux of gases through the cap and understanding whether the gas drainage layer within the cap is suitable for accommodating these gas fluxes. Within ESC-FI-024 we asked LLW Repository Ltd to produce a gas management strategy for both radioactive and non-radioactive gases. The resulting gas management strategy should provide a link between anticipated total gas production rates, the flux away from the waste and the adequacy of the gas drainage layer to collect and disperse the expected gases.

At present, LLW Repository Ltd monitors the gases released from the trenches at a number of trench gas probes. The 2011 ESC does not identify the need for or nature of future gas monitoring and sampling from either the trenches or future vaults. In Environment Agency (2015d) we identify the need for the provision of a gas monitoring and sampling capability within the vaults and the capped trench disposals. The gas management strategy produced in response to ESC-FI-024 should identify the need for gas monitoring and sampling capability before and after the placement of the final capping layer.

### *Leachate analysis*

The main design intent of the grouted container waste form is to reduce waste voidage and hence cap settlement. It additionally provides chemical conditioning and acts to adsorb some radioactive and non-radioactive species.

The grout deployed at the LLWR is a mixture of Pulverised Fuel Ash (PFA) and Ordinary Portland Cement (OPC). It is typically mixed in a 3:1 ratio of PFA to OPC (Small 2012). The PFA component of the grout contains a number of hazardous substances, such as chromium (Cr(VI)), arsenic (As) and cadmium (Cd). These substances could be leached from the grout and released into the environment via the groundwater pathway and thus pose a risk to receptors. Through IRF ESC-RI-INF-002, we requested LLW Repository Ltd to provide both further information on the constituent materials of the LLWR grout and to assess the risk that these substances, in particular Cr(VI), may present via the groundwater environment.

LLW Repository Ltd has addressed our first request by providing the relevant material safety data sheets of the constituents of the grout (Cemex MSDS1 and Cemex MSDS2). It also identified the sources within the UK of these constituents. The company has also assessed the risk associated with the leaching of Cr(VI) and other hazardous substances from the grout. The company used data obtained from experiments carried out by the Building Research Establishment (BRE) to establish the concentrations of hazardous components leached from grouted materials (Small 2012). The grout tested in these experiments had characteristics similar to those of the LLWR grout. LLW Repository Ltd concluded from this work that the risk presented by Cr(VI) leaching from the grout will be less than the risk presented by the corroding waste mass (Kelly 2013b). We agree with this conclusion.

We support the work that LLW Repository Ltd has so far carried out, but recommend that it should confirm that the experiments undertaken at BRE are suitably representative of the LLWR grout. We recommend that LLW Repository Ltd should consider performing leaching tests on samples of the LLWR grout. We also recommend that the company should continue to monitor the leachate from the vaults for all applicable Cr species. If spikes in Cr concentrations are detected, it should consider further analysis for Cr(VI) (**Recommendation INF28**).

### *FEPs and uncertainty tracking system*

In support of its 2011 ESC, LLW Repository Ltd has developed a tracking system for the management of Features, Events and Processes (FEPs) (LLW Repository Ltd 2013b). This system documents the uncertainties important to the 2011 ESC and is fundamental to providing confidence that significant uncertainties are being properly managed. We expect LLW Repository Ltd to have a programme in place to deal systematically with these uncertainties. The FEPs relevant to the near field that are identified in the tracking system relate to the trenches, the vaults

and, to a degree, the site engineering. We discuss relevant FEPs and uncertainties in all of our other subject review reports.

In the FEPs and uncertainty tracking system, LLW Repository Ltd uses 3 criteria to assess the significance of uncertainties. These are (Lean and Willans 2010):

- FEP and uncertainty judgement - expert judgment on the 'local' importance of the uncertainty (indicates how important it will be to represent this uncertainty in assessments of sub-system performance). These are classified as 'High' (significant uncertainty or variability and impact on sub-system performance), 'Medium' (some uncertainty or variability and some impact) or 'Low' (either little/no uncertainty or little/no impact).
- Uncertainty management (importance) - LLW Repository Ltd's judgement on the significance of the uncertainty associated with the FEP for safety assessment and the ESC. The uncertainties are classified as 'Negligible impact', 'Significant for safety assessment' or 'Significant for ESC'.
- Uncertainty management (satisfaction level) - LLW Repository Ltd's satisfaction level with the current treatment of the uncertainty associated with the FEP. The uncertainties are classified as 'Content', 'Minor concerns' (some work needed) or 'Serious concerns'.

For the trenches and vaults, the main uncertainty requiring further work that LLW Repository Ltd has identified, relates to the release and partitioning of C-14. We support this view and, as stated previously in discussions on C-14, we expect the company to undertake further work to improve its understanding in this area.

Our review of LLW Repository Ltd's use of the FEPs and uncertainty tracking system suggests several inconsistencies in how specific uncertainties have been treated. For example (LLW Repository Ltd 2013b):

- LLW Repository Ltd considers that there is 'significant uncertainty or variability and impact on sub-system Performance' in trench FEP GW\_NF\_T\_EC\_07 (Microbiological Processes and Evolution) and that the uncertainty is of significance to the 2011 ESC. LLW Repository Ltd has 'major' concerns with the treatment of this uncertainty in the 2011 ESC and considers that further work may be required. However, whilst the company considers the equivalent FEP for the vaults, GW\_NF\_V\_EC\_12 (Microbiological Processes and Evolution), to have the same level of uncertainty, it only appears to have 'minor' concerns over its treatment in the 2011 ESC, although again it acknowledges that further work may be required.
- LLW Repository Ltd considers that there is 'significant uncertainty or variability and impact on sub-system Performance' in trench FEP GW\_NF\_T\_RRM\_05 (Radionuclide Solubility), and that it has 'major' concerns with its treatment in the 2011 ESC. However, LLW Repository Ltd considers that there is only 'some uncertainty or variability and some impact' in the equivalent FEP for the vaults, GW\_NF\_V\_RRM\_06 (Radionuclide Solubility), and that it is 'content' with its treatment in the 2011 ESC. The company considers that uncertainty in both FEPs could be of significance to the ESC.

It is not clear why there are these apparent inconsistencies in the grading of LLW Repository Ltd's satisfaction level between the trenches and the vaults, given that the explanations provided in the FEPs and uncertainty tracking system are the same. In ESC-FI-008 we describe a number of potential improvements to the management of uncertainty in the near field environment.

We note that LLW Repository Ltd has very little site-specific data relating to the microbial processes that will happen within the vaults, compared with the site-specific data available for the trenches. This again leads us to question whether the uncertainty is correctly classified. As part of the development of a near field monitoring programme described in ESC-FI-018 we expect consideration of the need to gain site-specific vault microbial information.

We also note that recent work carried out by LLW Repository Ltd as part of the 2011 ESC submission has not been included in the FEPs and uncertainty tracking system and this will need to be addressed in the future. Examples are; the container condition work and the distribution of voidage across Vault 8. We will expect the extent and contents of the FEP and uncertainty tracker to be reviewed as part of the ongoing management of the ESC.

The FEPs and uncertainty tracking system identifies a number of uncertainties in FEPs that will affect the 2011 ESC, but LLW Repository Ltd has no current plans for further work to reduce those uncertainties that are deemed of low importance. An example is GW\_NF\_V\_RRM\_01 (Release from wasteform metals). From the information presented, there seems to be a potential for the company to reduce this uncertainty further. However, as it is not classed as high priority, no further work is planned. This may be appropriate, but we expect the company's forward plan supporting the further development of the ESC to consider the need to undertake analysis of the possible consequences of identified uncertainties and consider where they may be reduced or their effects lessened or compensated for. We recognise that the company will have to prioritise work to address the identified uncertainties and we do not expect LLW Repository Ltd to reduce uncertainties further where they will have little or no environmental benefit. This also applies to FEP uncertainties relating to the future disposal of low level waste streams.

Overall and as discussed further in Section 2.9 of Environment Agency (2015b), the FEP and uncertainty tracking system represents an excellent start to the management of uncertainties. However, we recommend improvements to the tracking system and its use. In particular, we recommend that LLW Repository Ltd should adopt a more systematic approach to the assessment of the work required to reduce important uncertainties. In future iterations of the ESC, we expect LLW Repository Ltd to further improve the management and assessment of important uncertainties for the ESC (ESC-FI-008).

### *Extended Disposal Area*

The assessment of the near field of the EDA covers Vaults 15 to 20 in addition to the trenches and Vaults 8 to 14. The EDA has been assessed in a similar manner to the RDA, where the primary model for understanding the development of the near field is the GRM (Small et al. 2011c).

The assessment of the EDA applies 2 inventory cases, case A (reference) and case B (reference plus new build waste). The main difference between the 2 inventories is in the quantities of metals and cellulose disposed of, with these being greater in Case B.

The partitioning of C-14 will be significantly different in the EDA from that for the RDA, due to the lower quantities of cellulose predicted to be disposed of to the EDA. Our comments in the C-14 section of this report are also applicable to the EDA.

Our overall view is that, for the EDA, LLW Repository Ltd has presented a reasonable understanding of the near field and how it will evolve over the lifetime of the facility. We note that the impacts of EDTA have also been assessed for the EDA and do not result in the risk guidance level being exceeded.

The assessment for the near field of the EDA does not present us with any significant concerns about its evolution or LLW Repository Ltd's understanding of it. However, further useful knowledge will be gained over the lifetime of the LLWR and we expect the company to apply this knowledge to the assessment of the EDA. Depending on future waste consignments to the LLWR, the number of vaults in the EDA may be reduced, with some LLW being diverted via other routes. LLW Repository Ltd should maintain an awareness of the volume and form of likely future waste consignments to the LLWR and the effect that this may have on the EDA near field (**Recommendation INF29**).

## 2.4. General observations

Our review of the inventory and near field reports within the 2011 ESC has identified a number of general observations that we consider are important to communicate to LLW Repository Ltd, to aid the production of future updates of the ESC.

### 2.4.1. Inventory

Overall we consider that the 2011 ESC is a significant improvement on the 2002 PCSC submission. In particular, the Level 2 report presents an appropriate level of information for the reader to gain an understanding of the inventory. However, in some cases information presented in the Level 3 reports would have been better presented in the Level 2 report, for example flow charts providing an overview of how the trench, Vault 8 and forward inventories have been derived

(Wareing et al. 2008). We recommend that LLW Repository Ltd considers making fuller use of similar flow charts in future iterations of the ESC (**Recommendation INF30**).

In addition, the inventory section of the 2011 ESC could be improved by providing worked examples of how LLW Repository Ltd calculates the activity of a sub-bay in the trenches. We recommend that this is provided as part of updates to the ESC, noting that LLW Repository Ltd has provided such examples in response to our audit of the trench inventory. The examples should cover both a sub-bay where the total activity is dominated by a specific waste consignment and also one where a number of routine consignments each make a significant contribution to the total activity (**Recommendation INF31**).

The number of Level 3 reports and the detail they contain provide adequate support to the Level 2 documentation. We therefore needed to request only limited further information on the inventory, with some exceptions related to Vault 8.

The 2011 ESC inventory investigations extensively used past site records and documents. Aside from further reviews of the information previously used, we consider that the most effective way of reducing trench inventory uncertainty further will be by collection and analysis of trench leachate.

Our review of the 2011 ESC inventory area would have benefitted from full access to the LLWTS. Access to this system will be even more important for future assessments of the ESC as a result of the proposed emplacement strategies and the proposed changes to the conditions on disposing complexants in the future.

#### **2.4.2. Near field**

In the near field area we found the extent of supporting Level 3 references inadequate in some areas, such that we had to request further supporting information. For example, we found it necessary to request further information related to complexants, uranium and colloids. We also found that the Level 2 report did not always appear to address issues proportionately to their risk, for example focussing more on uranium than some other more important radionuclides. We also found that to some extent the 2011 ESC near field report focussed on issues that were very relevant to the 2002 PCSC, but which are no longer as important in the 2011 ESC. In some areas we consider that this detracted from the clarity of some aspects with important safety and environmental implications. Given that the 2011 ESC is now a far more developed case than the 2002 PCSC we do not expect this issue to arise in the future to the same extent, but ask that LLW Repository Ltd continue to aim to improve the clarity and structure of future ESCs, to ensure important safety and environmental implications are obvious.

We consider that in the near field area of the 2011 ESC there would have been considerable benefits in presenting a fuller forward programme of work, which would have aided our review, informing us of ongoing activities. We therefore recommend that consideration is given to providing as full a forward work programme on near field issues as possible within future updates to the ESC (**Recommendation INF32**).

We note that LLW Repository Ltd has made use of elicitation exercises to gain an understanding of how specific phenomena in the near field, such as the degradation of waste containers, will develop. We support the use of this approach, but would not expect it to replace experimental work. LLW Repository Ltd should make sure that the use of elicitation exercises is proportionate and is combined with experimental and modelling work to reduce the uncertainties in the near field (**Recommendation INF33**).

We commend LLW Repository Ltd on its use of variant cases in the GRM to gain greater understanding of the sensitivity of the outputs from the near field to the values of various parameters. This particularly applies to the development of LLW Repository Ltd's understanding of the partitioning of C-14 in the near field.

## 3. Meeting our requirements

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

We define an ESC as 'the collection of arguments, provided by the developer or operator of a disposal facility that seeks to demonstrate that the required standard of environmental safety is achieved' (Environment Agency et al. 2009). In this section we provide a summary of our review of the inventory and near field sections of the 2011 ESC and assess whether Schedule 9 Requirement 6 of the current environmental permit and relevant parts of the GRA have been met.

### 3.1. Inventory

There are no specific requirements in the GRA that directly relate to the inventory. However, the inventory is directly relevant to addressing a number of broader requirements in the GRA. In particular, LLW Repository Ltd needs to demonstrate understanding of the inventory of past and potential future disposals to prepare an adequate ESC and develop a source term for the supporting assessment calculations.

In deriving the trench inventory LLW Repository Ltd has made good use of the existing disposals records and of the RECALL exercise. However, there remains significant uncertainty associated with the trench inventory. Available information on the non-radiological component of the trench inventory is particularly poor. To help compensate for this uncertainty we expect LLW Repository Ltd to have suitable monitoring arrangements in place to identify any potential fluctuations in discharges within the leachate. We also expect LLW Repository Ltd to continue to update the inventory for the trenches by assessing future waste radionuclide fingerprints and evaluating whether these present a better match for past disposals.

We note that the uncertainty associated with the derived inventory for Vault 8 is considerably less than that for the trenches and therefore the bounding value of an order of magnitude in the uncertainty that LLW Repository Ltd assumes appears reasonable and cautious. In any future updates of the ESC, we expect LLW Repository Ltd to improve the presentation to include a more detailed description of the non-standard disposals in Vault 8 and in addition to provide an improved representation of the distribution of key radionuclides and materials across the vault and within each individual stack where this will be beneficial to the assessment or wider understanding of the LLWR's inventory.

We consider that the derived forward inventory of waste to be disposed of to the LLWR is adequate for the present. We encourage LLW Repository Ltd to continue engagement with the NDA and waste consignors to improve the accuracy of the forward inventory wherever practicable. In particular, we expect further improvements in the non-radiological component of the forward inventory when compared to past disposals. We note that current waste acceptance procedures should facilitate greatly improved collection of inventory information from consignors.

We consider that the radionuclide inventory collated in the 2011 ESC provides a suitable source term for the radiological assessment calculations. Estimates of uncertainty in the radionuclide inventory and alternative inventory scenarios defined to account for variations in the forward inventory appear reasonable. This inventory information has been used to derive the source term for the quantitative radiological assessment calculations and hence helps to address GRA requirements R3 (environmental safety case), R5 (dose constraints during the period of authorisation), R6 (risk guidance level after the period of authorisation), R7 (human intrusion after the period of authorisation), R8 (optimisation), R9 (environmental radioactivity) and R13 (waste acceptance criteria).

LLW Repository Ltd acknowledges that there is significant uncertainty in the non-radiological component of the inventory. We accept the limitations of available information and support the company's liaison with consignors and the NDA to gain an improved understanding of the non-radiological component of future disposals. We consider that the current assessment of the non-

radiological inventory is adequate to demonstrate that GRA requirement R10 (protection against non-radiological hazards) is met. We note that we asked LLW Repository Ltd in ESC-FI-006 to produce an updated non-radiological hydrogeological risk assessment before the end of 2017 and we would expect to see improvements in the source term used in this assessment wherever practicable.

LLW Repository Ltd has a vast quantity of records that must be maintained throughout the lifetime of the facility and potentially until surrender of the environmental permit and beyond. The trench records are primarily stored on paper or microfiche; for Vault 8, the main records are consignors' records of disposals maintained within the LLWTS; and, for the future inventory, LLW Repository Ltd retrieves information from the national radioactive waste inventory maintained by the NDA.

The LLWTS is also a key component in the tracking and collating of waste information. At present the database provides a good repository for this information, but we have recommended a number of improvements to the system. In particular, we seek reassurance that the LLWTS can track the emplacement strategies proposed in the 2011 ESC and, if this is not forthcoming, that an alternative system will be implemented. The tracking system (or alternative systems) should be able to record important waste information critical to the 2011 ESC, such as that related to voidage.

We consider that LLW Repository Ltd is meeting the GRA requirements for documentation and record keeping (GRA paragraph 6.2.37) concerning inventory information. The company has relevant procedures in place to monitor records and make sure that none of the records become obsolete.

We note that a significant part of the experience in deriving the trench inventory lies with a third party other than LLW Repository Ltd. Although the company currently has access to relevant expertise, we support plans to bring the expertise for deriving the trench inventory in house. We expect LLW Repository Ltd to make sure that suitable knowledge management and succession planning is maintained across all aspects of the waste inventory to ensure continuing compliance with GRA requirement R4 (environmental safety culture and management system).

In summary, we consider that LLW Repository Ltd has adequately addressed those parts of the GRA that are relevant to the inventory for the purpose of permitting the LLWR. However, there are a number of areas, as discussed in Section 2 and summarised in Appendix 2 (Recommendations), where further improvements should be made to make sure that the ESC continues to meet the requirements of the GRA in the future.

### 3.2. Near field

There are no specific requirements in the GRA that directly relate to the near field topic area. However, information about the near field is directly relevant to addressing a number of broader requirements. In particular, LLW Repository Ltd needs to demonstrate understanding of the physical and chemical characteristics of the repository to prepare an adequate ESC (GRA paragraph 7.2.6).

LLW Repository Ltd's understanding of the evolution of the near field has improved since the 2002 PCSC. In particular, through variant cases, it investigated how changes to major parameters will affect this evolution. Overall, LLW Repository Ltd's assessment has provided us with confidence that it has a good understanding of the evolution of the near field before and after closure of the facility.

As part of our review, we raised a number of FIs and recommendations that we expect LLW Repository Ltd to address in developing site understanding and the ESC. LLW Repository Ltd has also identified the majority of these issues within its engineering forward programme (Shaw 2013). Some of the main areas we expect to see addressed are:

- Remediation of the trench interim cap to reduce the influx of water into the trench waste mass, through application of BAT. We expect LLW Repository Ltd to provide a BAT strategy capable of minimising impacts as a result of ingress of water into the trench waste for the whole period before the placement of the final capping system.

- Optimisation of the container design and other aspects of the protection of waste (ESC-FI-001 and ESC-FI-025).
- Continuing improvement in LLW Repository Ltd's knowledge of the voidage present in disposal containers, in particular in Vault 8. LLW Repository Ltd should make sure that the design of the engineered cap can accommodate any uncertainty that remains about the degree of voidage within the waste mass (ESC-FI-001 and ESC-FI-027).
- Demonstration that the higher stacking proposed in the 2011 ESC for Vault 8 can be safely implemented without compromising cap stability (ESC-FI-001 and ESC-FI-027).
- Implementation of relevant procedures to ensure that future waste treatment processes or diversion of certain waste from the LLWR is understood and the effects on near field evolution assessed.
- Provision of a proportionate monitoring programme for colloids to make sure that the conclusions reached in the 2011 ESC remain valid over the period of authorisation (ESC-FI-015).
- Continued engagement with waste consignors to make sure that the data used in the assessment of the impacts of EDTA and other complexants remains valid for past and future disposals. We also expect LLW Repository Ltd to maintain an awareness of the potential for other complexants to be present in disposals to the facility (ESC-FI-009).
- Assessment of the sensitivity of the outputs from the models to discretisation (ESC-FI-016).

We also made several recommendations covering aspects of the near field that LLW Repository Ltd should consider as part of its forward work programme.

Understanding the near field is of direct relevance to understanding the evolution of the LLWR and the potential for contaminant migration from the facility. LLW Repository Ltd states that 'our understanding of the near field ... underpins our estimates of environmental impacts, including those defined in Requirement 6. Near field studies also underpin our approach to optimisation (Requirement 8) and waste acceptance criteria (Requirement 13)' (LLW Repository Ltd 2011b). LLW Repository Ltd also states that 'our programme of experimental research, which underpins our modelling studies, demonstrates the application of sound science, which is an important aspect of Requirement 4' (environmental safety culture and management system). As we remark above, we agree that LLW Repository Ltd has presented a good understanding of the near field and its evolution. We consider that the near field work presented in the 2011 ESC and in subsequent submissions meets the relevant aspects of requirements R6 (risk guidance level after the period of authorisation), R8 and R13 as well as the related aspects of R3 (environmental safety case), R7 (human intrusion after the period of authorisation) and R9 (environmental radioactivity).

LLW Repository Ltd is actively using near field information to underpin proposed changes to the WAC. Further controls are proposed on voidage, taking into account concerns we raised as a result of the condition of containers stored and disposed in Vault 8. We note that LLW Repository Ltd is seeking to improve communication with consignors to further address this area and we will press for further improvements. The company has submitted proposals for changes to the WAC to allow disposal of complexants (including EDTA) at the LLWR. The case presented supports these changes to the WAC. However, to address this matter fully, we will seek further assurance that the disposal of complexants will not have unacceptable effects on the environment, by requiring LLW Repository Ltd to establish a proportionate monitoring programme and to undertake further engagement with consignors (ESC-FI-009).

We consider that LLW Repository Ltd has made use of good science and suitable experts for developing an understanding of the near field. This meets the requirement for application of sound science and engineering practice to the development of the ESC (GRA paragraph 6.2.26) and we commend this work.

LLW Repository Ltd has used data from the near field research programme, monitoring programme and site investigation programme to support the development of the near field conceptual model. We agree that LLW Repository Ltd has made best use of the data available at present to support its modelling of the evolution of the near field. This work provides evidence in support of meeting GRA requirements R11 (site investigation) and R14 (monitoring).

LLW Repository Ltd's future monitoring programme will play a key role in enhancing its understanding of the evolution of the near field and in supporting the further development of the near field models. We expect future monitoring data to address several areas of uncertainty, including further sampling for complexants in the trenches and monitoring of the Vault 8 cap to establish whether the cap is performing as predicted in the 2011 ESC. We note that monitoring will play an important role in supporting the evolving ESC throughout the period of authorisation, as discussed further in our review of the monitoring programme (Section 2.4.4 and 2.4.5 of Environment Agency 2015c).

In summary, we consider that LLW Repository Ltd has addressed those parts of the GRA relevant to the near field to an extent adequate for the purpose of permitting the LLWR. However, as discussed in Section 2 and summarised in Appendix 2 (Recommendations) and Appendix 3 (Forward Issues), there are a number of areas where improvements should be made to make sure that the ESC continues to meet the requirements of the GRA in the future.

## 4. Conclusions

LLW Repository Ltd submitted the 2011 Environmental Safety Case (ESC) against Schedule 9 Requirement 6 of the current Low Level Waste Repository (LLWR) environmental permit. We consider that, in the 2011 ESC, LLW Repository Ltd demonstrates an adequate understanding of the inventory of past and potential future disposals, together with the biogeochemical environment of the near field and its likely evolution. This understanding is consistent with demonstrating that an appropriate standard of environmental safety can be achieved at the LLWR now and in the future.

We consider that LLW Repository Ltd has addressed the requirements of our Guidance on Requirements for Authorisation: Near-Surface Disposals Facilities on Land for Solid Radioactive Waste (GRA) relating to the inventory and near field to an extent adequate for us to determine an environmental permit variation application for continuing disposals of radioactive waste at the LLWR. However, we identified a number of areas for improvement as highlighted in this document. These areas are outlined in our recommendations and Forward issues (FIs). We expect LLW Repository Ltd to demonstrate progress against these.

The overall quality of the 2011 ESC submission in the inventory and near field areas is high. The technical work is of a high standard and has been well documented. The clarity of the safety arguments is generally good and the supporting information can generally be traced back to the source documents. However, the level of detail in the Level 1 and 2 documents was insufficient to allow us to assess the 2011 ESC arguments properly. We had to review Level 3 documents and request further documents not included in the original 2011 ESC submission to obtain enough information for our review.

LLW Repository Ltd has made good use of the information available about the waste inventory. We are confident that the derived inventory is as good as could reasonably be achieved given the information available. We understand that significant uncertainties remain, in particular relating to past disposals to the trenches. However, we were able to conclude that, on the basis of information currently available to LLW Repository Ltd, the assumed order of magnitude of uncertainty for the radiological inventory of the trenches is reasonable and forms an appropriate basis for the ESC assessment.

LLW Repository Ltd has assessed uncertainty in the future inventory by considering a set of alternative scenarios that we consider to be appropriate. We raised no forward issues directly relating to the waste inventory, but made a number of recommendations to LLW Repository Ltd with the aim of ensuring that inventory information continues to support the ESC appropriately in the future.

LLW Repository Ltd has carried out a substantial programme of work to improve understanding of the waste and waste forms and to determine the implications for the evolution of the near field. Consequently, LLW Repository Ltd's understanding has improved significantly since the 2002 Post Closure Safety case (PCSC).

We consider that LLW Repository Ltd has identified and characterised the main factors liable to affect the biogeochemical evolution of the near field, resulting in a good understanding of how the near field will evolve over the lifetime of the facility. We identified a number of areas of good practice, for example the use of variant cases to investigate the implications of significant uncertainties on the evolution of the near field and the release of pollutants from the facility.

As a result of a joint inspection with LLW Repository Ltd we raised concerns relating to the degraded condition of some containers in Vault 8. In response to this inspection and other evidence collected by LLW Repository Ltd on container condition, the company instigated a major programme of work to assess the effects of container condition and voidage on the physical evolution of the near field. We support this ongoing programme of work, but note that significant uncertainties remain, having implications for the performance of the engineered barrier system. An FI (ESC-FI-001) has been raised that sets out our expectations for further investigations needed before the start of capping.

Although LLW Repository Ltd has made significant progress in understanding the near field, we identified a number of areas for potential further improvement. These are documented in a number of FIs and recommendations. We expect LLW Repository Ltd to address these issues in its forward work programme so as to strengthen the ESC and to make sure that it continues to meet the requirements of the GRA.

In summary, we regard the derived inventory as a good representation of the potential waste inventory to be disposed of to the LLWR. We also consider that LLW Repository Ltd has demonstrated a good understanding of the repository near field and its evolution, together with the implications for releases of radioactivity and other pollutants from the facility. We commend LLW Repository Ltd's work in this area and expect this standard to be maintained and improved on in future updates of the ESC.

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

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# 6. Appendix 1 - Issue Resolution Forms

## 6.1. Introduction

As outlined in Section 1.3, Issue Resolution Forms (IRFs) are detailed records of concerns and queries raised as part of our review of the 2011 ESC. Each IRF includes one or more actions. LLW Repository Ltd was required to provide a substantive response to the action(s) specified on the IRF by the specified date(s). Issues were only closed out when we had determined that the LLW Repository Ltd response adequately addresses the issue.

## 6.2. Inventory and near field Issue Resolution Forms

Summaries of Regulatory Issues (RIs), Regulatory Observations (ROs) and Technical Queries (TQs) raised during our review of the 2011 ESC inventory and near field work are provided in Tables 2, 3 and 4 respectively. These IRFs are reproduced in full in Environment Agency (2015f). The IRFs are not sequentially numbered. This is because some IRFs were identified as possible queries but not issued, for example, following further detailed review of information provided in support of the 2011 ESC, or following on from clarifications provided by LLW Repository Ltd. All IRFs have now been closed.

**Table 2 Regulatory Issues**

Regulatory Issue number	Title	Summary
<b>ESC-RI-INF-001</b>	Impact of 2010 Inventory	We requested an assessment of the implications of the 2010 UK Radioactive Waste Inventory for the 2011 ESC and a demonstration that the 2011 ESC (as amended if necessary) is consistent with the best available information on future waste arisings.
<b>ESC-RI-INF-002</b>	Impact of Grout on Vault Leachate Composition	We requested further information on the impact of the leaching of components from the grout on the composition of vault leachate. In particular we were concerned about the impact of hazardous components such as Cr(VI).
<b>ESC-RI-INF-005</b>	Container Condition Monitoring and Sampling Programme	We requested further information on the condition of the ISO freight containers in Vault 8 and confirmation that the grouted container performance assumptions used in the 2011 ESC can be achieved over the whole operational life of the site. We also requested an appropriate programme of inspection, monitoring and sampling of container condition.

**Table 3 Regulatory Observations**

Regulatory Observation number	Title	Summary
<b>ESC-RO-INF-002</b>	Authorised Disposals, Storage and Forward Inventory of Vault 8	We sought further clarity on what waste is stored, what waste is disposed and what waste is part of the forward inventory in Vault 8.
<b>ESC-RO-INF-003</b>	Non-Standard Disposals to Vault 8	We requested information on the procedures in place for dealing with non-standard disposals at the LLWR. This IRF also requested a list of all non-standard disposals that had been consigned to Vault 8.
<b>ESC-RO-INF-003b</b>	Non-Standard Disposals to Vault 8	The response in ESC-RO-INF-003 did not state the procedures in place for dealing with non-standard disposals before 2011. Thus this IRF requested this further information.

**Table 4 Technical Queries**

Technical Query number	Title	Summary
<b>ESC-TQ-INF-003</b>	Radionuclide Forward Inventory Data	We requested further information relating to a number of key waste streams that are a component of the forward inventory.
<b>ESC-TQ-INF-004</b>	Analysis of RECALL Interviews	We requested further clarification on the conclusions reached by LLW Repository Ltd concerning the RECALL exercise.
<b>ESC-TQ-INF-005</b>	MoD Waste Streams	We requested further information on disposals made by the MoD to Vault 8. We requested volume and activity data, as well as further information about the actual streams themselves.
<b>ESC-TQ-INF-005a</b>	Response to MoD Waste Streams	We requested further detail on the MoD waste streams that were originally queried in ESC-TQ-INF-005.
<b>ESC-TQ-INF-006</b>	Ratio of Waste to Grout Infill	We requested further information on the impact of waste packages in which the ratio of waste to grout is less than the average stated in the 2011 ESC of 60:40 waste:grout. We sought evidence that these waste packages would not impact on the near field engineering and the chemical evolution of the near field.
<b>ESC-TQ-INF-007</b>	Understanding and Optimisation of Surcharge Requirements and Final Cap Placement Timing	We sought clarification of the design and monitoring of surcharging material placed over the trench waste prior to the placement of the final capping system.

Technical Query number	Title	Summary
<b>ESC-TQ-INF-018</b>	Trench Cap Leakage Values	We asked LLW Repository Ltd to amend the trench cap infiltration values used in the 2011 ESC to represent the latest available data and so as to reflect the best available measured leakage rate.
<b>ESC-TQ-INF-020</b>	Future Inventory - Combination of Case B, C and D	We requested vault fill dates for the combined future inventory scenario (Cases B, C and D) and an assessment of the implications of the combined scenario and its impact on the 2011 ESC and on restoration timescales.
<b>ESC-TQ-INF-021</b>	Key Radionuclides Am-241 Contribution to Vault 8 and Overall Inventory	We sought further clarification on the importance of the disposed Am-241 contribution from Vault 8 to the overall inventory from the vaults.
<b>ESC-TQ-INF-024</b>	Uncertainty in Isotopic Plutonium Ratios within the Trench Inventory	We sought clarification on the effect of the uncertainty associated with the burn-up and cooling periods of fuel on the plutonium isotopic ratio.
<b>ESC-TQ-INF-026</b>	Understanding and Modelling the Behaviour of Disposed Uranium	We sought further justification of the solubility and sorption values used in the 2011 ESC for uranium. We also requested that LLW Repository Ltd assess a combined case of high solubility and low sorption on the risk associated with the groundwater assessment pathway.
<b>ESC-TQ-INF-032</b>	Containers Located within Vault 8 and Tracking	We requested further evidence that the proposed stacking of out-of-specification containers in Vault 8 had been tracked and the proposed emplacement strategy had been implemented in Vault 8 as stated in the 2011 ESC.
<b>ESC-TQ-INF-035</b>	Impacts on the Radon Gas Pathway	We sought clarification on a number of statements presented in the 2011 ESC concerning radon gas release through the engineered cap. We sought confidence that the radon assessment in the 2011 ESC presented a worst case scenario.

# 7. Appendix 2 - Recommendations

## 7.1. Introduction

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

## 7.2. Inventory and near field recommendations

Table 5 summarises the recommendations made in this report. Further details are provided in Section 2.

**Table 5 Inventory and near field recommendations**

Recommendation number	Summary of recommendation
<b>INF1</b>	LLW Repository Ltd should make sure that knowledge on the process for deriving the trench inventory is maintained in the future, for example by bringing it 'in-house'.
<b>INF2</b>	LLW Repository Ltd should consider assessing the application of the updated radionuclide fingerprints to the trench inventory as part of any wider review of the trench inventory where it may lead to potential improvements
<b>INF3</b>	LLW Repository Ltd should continue to carry out audits to make sure that the physical locations of containers in the vaults are in agreement with information in its waste tracking system.
<b>INF4</b>	LLW Repository should address query 10 within ESC-TQ-INF-004 which relates to consideration of the combination of effects, for key radionuclides, from multiple issues arising from the RECALL work.
<b>INF5</b>	We expect future updates of the ESC to identify and assess the nature and extent of non-standard disposals in Vault 8 and future vaults, to appropriately inform cap settlement assessments.
<b>INF6</b>	In future updates of the ESC, LLW Repository Ltd should consider whether future radionuclide fingerprints are suitably representative of the Vault 8 waste streams currently without a matched radionuclide fingerprint (in an analogous fashion to our recommendation for the trench inventory in Section 2.2.1).
<b>INF7</b>	LLW Repository Ltd should continue to engage with consigners and the NDA to reduce the uncertainty associated with the future waste inventory (radiological and non-radiological components).
<b>INF8</b>	LLW Repository Ltd should engage with consigners and the NDA to minimise the implications of unknown alpha and beta/gamma in the forward inventory.
<b>INF9</b>	LLW Repository Ltd should maintain an awareness of any developments nationally and internationally that can help reduce the uncertainty associated with the CI-36 inventory.
<b>INF10</b>	LLW Repository Ltd should give further consideration to options for improving the non-radioactive inventory, for example through the

Recommendation number	Summary of recommendation
	use of appropriate waste fingerprints.
<b>INF11</b>	A small proportion of the Vault 8 non-radiological inventory has been derived using a back-fitting process similar to that used for the trenches. We expect LLW Repository Ltd to review the back fitted Vault 8 inventory component against future waste stream compositions and to refine it where possible.
<b>INF12</b>	LLW Repository Ltd should engage with the NDA to ensure that future updates of the UKRWI better address the non-radiological components, in order to support future non-radiological assessments within the ESC.
<b>INF13</b>	LLW Repository Ltd should consider a more systematic treatment of uncertainty in the non-radiological component of the inventory. This may potentially be achieved using variant cases.
<b>INF14</b>	LLW Repository Ltd should use a systematic approach when defining 'other' components in the LLWTS and the development of future LLW tracking systems.
<b>INF15</b>	Should the GRM model be used to support future ESC updates, LLW Repository Ltd should consider implementing the recommendations in Small et al. (2009) to make sure that the time steps applied in GRM are optimised. If a different model is used in future ESC updates then LLW Repository Ltd should ensure that applicable findings of Small et al (2009) are reviewed.
<b>INF16</b>	LLW Repository Ltd should assess the leachability of Sikament-700 from both fresh and aged samples of grout, this work could be carried out as part of wider investigations into the leachability of the LLWR grout formulation.
<b>INF17</b>	If bulk quantities of complexants are disposed of to the LLWR, LLW Repository Ltd should assess the possible effects of heterogeneity in the vaults. This could assess, in particular, whether the placement of bulk quantities of complexant next to disposals containing high quantities of strongly complexed pollutants (for example lead), could affect the results of the 2011 ESC assessments.
<b>INF18</b>	LLW Repository Ltd should consider periodic sampling and analysis for DTPA in trench leachate.
<b>INF19</b>	LLW Repository Ltd should provide further supporting evidence for its choice of Kd and solubility parameters for non-radiological contaminants.
<b>INF20</b>	We expect future updates of the ESC to include an increased understanding of the impact on near field performance of low grout to waste ratio containers that were identified during the container condition investigations.
<b>INF21</b>	We recommend that future modelling of container settlement incorporates a more realistic degree of discretisation and greater consideration of the geotechnical response of containers to the loss of waste volume resulting from cellulose degradation.

Recommendation number	Summary of recommendation
INF22	LLW Repository Ltd should consider further experimental and/or near field monitoring work, similar to the GRE work carried out at Olkiluoto, to support the future near field modelling, particularly in relation to the partitioning of C-14 and the behaviour of C-14 in unsaturated vault conditions.
INF23	LLW Repository Ltd should consider an appropriate gas sampling campaign from Vault 8 after the vault has been capped. LLW Repository Ltd should consider use of any data obtained from this monitoring programme to support the modelling carried out in the 2011 ESC.
INF24	LLW Repository Ltd should make sure that extremes of waste to grout ratios within containers are considered and as necessary assessed, in particular in relation to C-14 behaviour.
INF25	LLW Repository Ltd should consider the potential use of vault and laboratory based investigations into the nature and extent of microbiological processes in the grouted waste form.
INF26	LLW Repository Ltd should maintain a watching brief of developments to understand what other materials, for example graphite, may act as sources of nutrients for microbial processes.
INF27	LLW Repository Ltd should investigate the effect of human intrusion on the evolution of the near field and the consequences for the risks associated with the gas and groundwater pathways. Any additional assumptions needed for this investigation should be simple and plausible, building on the human intrusion scenarios already assumed to have occurred. Variant scenarios need not be explored unless small changes in assumptions could make the longer term outcome radically worse.
INF28	LLW Repository Ltd should continue to monitor the leachate from the vaults for all applicable Cr species. If spikes in Cr concentrations are detected, it should consider further analysis for Cr(VI).
INF29	LLW Repository Ltd should maintain an awareness of the volume and form of likely future waste consignments to the LLWR and the effect that this may have on the EDA near field.
INF30	LLW Repository Ltd should consider incorporating the flow charts describing the development of the trench inventory, similar to those presented in Wareing et al. (2008), into future ESC updates.
INF31	LLW Repository Ltd should consider providing worked examples of how it calculates the activity of a sub-bay in the trenches in future updates to the ESC. Examples could cover both a sub-bay where the total activity is dominated by a specific waste consignment and also one where a number of routine consignments each make a significant contribution to the total activity.
INF32	LLW Repository Ltd should provide as full a forward work programme on near field issues as possible within future updates to the ESC.
INF33	LLW Repository Ltd's use of elicitation to gain an understanding of near field processes should be proportionate and should be

Recommendation number	Summary of recommendation
	combined with experimental and modelling work to reduce the uncertainties in the near field.

# 8. Appendix 3 - Forward Issues

## 8.1. Introduction

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

FIs are categorised in terms of the importance of the issue (for example the scope for improvement of the ESC against the GRA) and likely effort required to address the issue (Table 6).

**Table 6 FI categories**

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

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

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

## 8.2. Inventory and near field Forward Issues (FIs)

A summary of FIs raised during our review of the 2011 ESC inventory and near field work is provided in Table 7. Some of the FIs summarised below have been raised principally as a result of our review of the 2011 ESC engineering work but are included here since there are links with the inventory and near field areas. FIs are reproduced in full in Environment Agency (2015g).

**Table 7 Inventory and near field Forward Issues**

Forward Issue number	Title	Categorisation	Summary of issue
ESC-FI-001	Cap settlement Issues	A1	LLW Repository Ltd should develop and implement a work programme to identify an optimised cap design and container stack heights.
ESC-FI-005	Use of monitoring to reduce uncertainties in the ESC	B1	LLW Repository Ltd to collate and integrate monitoring objectives, strategies and procedures in a single document so as to provide evidence of how the forward monitoring programme will be implemented and developed throughout the period of authorisation and linked to the ESC to reduce uncertainties.
ESC-FI-006	Non-radioactive groundwater assessment reporting	A1	LLW Repository Ltd should update the hydrogeological risk assessment for the LLWR for issue by December 2017.
ESC-FI-007	Inaccessible voidage minimisation procedures and emplacement strategies	B1	LLW Repository Ltd should have appropriate procedures in place to make sure that potential container settlement remains within acceptable limits and that placement is optimised.
ESC-FI-008	Management of uncertainty	A2	LLW Repository Ltd should further develop the FEPs and uncertainty tracking system (or alternate tools) as a tool to

Forward Issue number	Title	Categorisation	Summary of issue
			manage uncertainty in the ESC and feed into the forward programme.
<b>ESC-FI-009</b>	EDTA analysis to support the complexant assessment	B1	LLW Repository Ltd should undertake further work to underpin the conclusions of its assessment of complexants such as EDTA. Further work is required to continue to improve LLW Repository Ltd's knowledge of complexants leaching from the trenches and the vaults and the risk this may have via the groundwater pathway.
<b>ESC-FI-010</b>	Waste heterogeneity in Vault 8 and future vaults	B2	LLW Repository Ltd should undertake further work to understand the distribution of key radionuclides and key materials in Vault 8 and future vaults. This work will allow LLW Repository Ltd to demonstrate via the ESC its understanding of the distribution of these species and materials in the vaults.
<b>ESC-FI-013</b>	Assessment of discrete items in stored and disposed waste	A1	LLW Repository Ltd should review the disposed records for stored waste located in Vault 8. LLW Repository should provide a BAT case for disposal of these items within Vault 8.
<b>ESC-FI-014</b>	Impact of changing waste composition	B2	LLW Repository Ltd should assess the implication of future waste treatment processes on the settlement of the engineered cap and on the performance of the near field.
<b>ESC-FI-015</b>	Monitoring of colloids	B2	LLW Repository Ltd should implement a proportionate colloidal material monitoring programme, to ensure that the conclusions reached in the 2011 ESC will remain valid.
<b>ESC-FI-016</b>	Discretisation of the GRM model	B2	LLW Repository Ltd should assess the sensitivity of the outputs from the GRM to the discretisation of the model grid.
<b>ESC-FI-018</b>	Near field vault and trench experimental	B1	LLW Repository Ltd should propose and implement a near field experimental and

Forward Issue number	Title	Categorisation	Summary of issue
	programme		monitoring programme capable of providing sufficient understanding of the vault and trench near field environments to support the ESC throughout the period of authorisation.
<b>ESC-FI-020</b>	Development of a new Low Level Waste Tracking System	A1	LLW Repository Ltd should develop a new waste tracking system that is fit for purpose for future waste tracking.
<b>ESC-FI-023</b>	Demonstration of BAT for current and future vault leachate management	A1	LLW Repository Ltd should produce a leachate management strategy that demonstrates the application of BAT to the management of leachate during the period of authorisation. The company should also investigate long-term leachate drainage performance, degradation and failure mechanisms.
<b>ESC-FI-024</b>	Gas management strategy	A2	LLW Repository Ltd should establish and implement a programme of work to develop a gas management strategy and infrastructure including collection of necessary monitoring data, for the period of authorisation.
<b>ESC-FI-025</b>	Protection of waste before final capping	A1	LLW Repository Ltd should develop and implement a programme of work to develop an optimised container design and restoration sequence that provides adequate protection to waste containers and minimises discharges to the environment.
<b>ESC-FI-026</b>	Engineering delivery	A1	LLW Repository Ltd should develop and implement the engineering forward programme to finalise the as-built design so as to allow further construction to begin. This programme should include: <ul style="list-style-type: none"> <li>• an engineering R&amp;D programme</li> <li>• an engineering performance monitoring programme</li> <li>• the scoping of a proportional Engineering Performance Assessment framework for use in future updates to the</li> </ul>

Forward Issue number	Title	Categorisation	Summary of issue
			ESC.
<b>ESC-FI-027</b>	Cap performance assessment	A1	LLW Repository Ltd should undertake further assessment of the performance of the capping system, including consideration of potential failure scenarios. Where appropriate, the company should incorporate the outcome of the investigations into the repository engineering design and updates to the ESC.
<b>ESC-FI-028</b>	Understanding the erosion sequence	A2	LLW Repository Ltd should seek to improve its conceptualisation and understanding of the repository erosion sequence.

# List of abbreviations

<b>ALARA</b>	As low as reasonably achievable
<b>BAT</b>	Best available techniques
<b>BNFL</b>	British Nuclear Fuels Limited
<b>CfA</b>	Conditions for acceptance by LLW Repository Ltd of radioactive waste for disposal at the LLWR
<b>Defra</b>	Department for Environment, Food and Rural Affairs
<b>DTPA</b>	Diethylene triamine penta-acetic acid
<b>EC</b>	European Community
<b>EDA</b>	Extended disposal area
<b>EDTA</b>	Ethylene diamine tetra-acetic acid
<b>ESC</b>	Environmental safety case
<b>EPA</b>	Engineering performance assessment
<b>EPR10</b>	Environmental Permitting (England and Wales) Regulations 2010, as amended
<b>FEP</b>	Features, events and processes
<b>FI</b>	Forward issue
<b>GRA</b>	Guidance on requirements for authorisation (of near-surface disposal facilities on land for solid radioactive wastes)
<b>GRE</b>	Gas reaction experiments
<b>GRM</b>	Generalised Repository Model
<b>IAF</b>	Issue assessment form
<b>ICRP</b>	International Commission on Radiological Protection
<b>ILW</b>	Intermediate level waste
<b>INF</b>	Inventory and near field
<b>IRF</b>	Issue resolution form
<b>ISO</b>	International Standards Organization
<b>Kd</b>	Partition coefficient or ratio
<b>LLW</b>	Low level waste
<b>LLWR</b>	Low Level Waste Repository near Drigg, Cumbria
<b>LLWTS</b>	Low level waste tracking system
<b>LTTE</b>	Long-term trench experiments
<b>LTVE</b>	Long-term vault experiments
<b>MoD</b>	Ministry of Defence
<b>MODARIA</b>	Modelling and Data for Radiological Impact Assessments

	(IAEA project)
<b>MSDS</b>	Material Safety Data Sheet
<b>NDA</b>	Nuclear Decommissioning Authority
<b>NNL</b>	National Nuclear Laboratory
<b>NTA</b>	Nitrilotriacetic acid
<b>OPC</b>	Ordinary Portland Cement
<b>PCSC</b>	Post-closure safety case
<b>PEG</b>	Potentially exposed groups
<b>PFA</b>	Pulverised fuel ash
<b>PHAST</b>	A Computer Program for Simulating Groundwater Flow, Solute Transport, and Multicomponent Geochemical Reactions
<b>PHREEQC</b>	A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations
<b>PIER</b>	Projected Inventory Evaluation Routine
<b>QPAC</b>	Quintessa's general-purpose modelling tool
<b>R&amp;D</b>	Research and development
<b>RDA</b>	Reference disposal area
<b>RECALL</b>	A programme used to elicit information on disposal practices at the LLWR from individuals with experience in the area
<b>RI</b>	Regulatory issue
<b>RO</b>	Regulatory observation
<b>RSA 93</b>	Radioactive Substances Act 1993 (as amended)
<b>RWMD</b>	Radioactive Waste Management Directorate (of the NDA), now Radioactive Waste Management Ltd
<b>SI</b>	International System of Units
<b>SLC</b>	Site Licence Company
<b>TBP</b>	Tributyl phosphate
<b>TBQ</b>	Terabequerel
<b>TPV</b>	Total potential voidage
<b>TQ</b>	Technical query
<b>TVO</b>	Finnish utility Teollisuuden Voima Oyj
<b>UKRWI</b>	United Kingdom radioactive waste and materials inventory
<b>WAC</b>	Waste acceptance criteria
<b>WAMAC</b>	Waste monitoring and compaction plant at Sellafield
<b>WIDRAM</b>	Waste Inventory Disposition Route Assessment Model
<b>µSv</b>	Microsievert

# Glossary

<b>Term</b>	<b>Definition</b>
<b>Absorbed dose</b>	The quantity of ionising radiation absorbed by a body, measured (usually in grays) as the energy absorbed per unit mass.
<b>Activity</b>	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.
<b>Adsorb</b>	To gather (a gas, liquid, or dissolved substance) on a surface in a condensed layer.
<b>Advective flux</b>	The mass transport of a substance in response to a pressure gradient. The pressure gradient results in movement of groundwater.
<b>Aerobic</b>	An environment or condition where oxygen is present.
<b>Alkali</b>	A substance with a relatively low concentration of hydrogen ions and a pH greater than 7.
<b>Alpha particle</b>	A positively charged particle consisting of two protons and two neutrons, emitted in radioactive decay or nuclear fission; the nucleus of a helium atom.
<b>Anaerobic</b>	An environment or condition where oxygen is absent.
<b>Becquerel (Bq)</b>	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).
<b>Best available techniques (BAT)</b>	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.
<b>Beta particle</b>	An electron or positron emitted from an atomic nucleus in a certain type of radioactive decay.
<b>Buffer</b>	A solution that is resistant to changes in pH.
<b>Cap</b>	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.
<b>Chelating agents</b>	A chelating agent is a substance whose molecules can form several bonds to a single metal ion.
<b>Colloid</b>	A small particle or molecule dispersed in a second medium that has at least one dimension between approximately 1 nm and 1 $\mu$ m.

<b>Complexant</b>	'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.
<b>Complexation</b>	Is the process by which a ligand (complexant) and metal bind together to form a new chemical species.
<b>Conceptual model</b>	A set of qualitative assumptions used to describe a system, or part of a system, in the real world.
<b>Conservative (of assumptions and data)</b>	Cautious in the sense that impacts would be overestimated.
<b>Consignor (of waste)</b>	An organisation or person that sends waste to the repository.
<b>Consignment</b>	A consignment is a container or item of waste sent by a waste producer (consignor) to a disposal facility (such as LLWR).
<b>Daughter isotope</b>	An isotope that is the product of the radioactive decay of a parent.
<b>Decay chain</b>	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.
<b>Differential settlement</b>	Different settlement between two adjacent stacks in the vaults or between adjacent locations of waste in the trenches.
<b>Diffusion</b>	Transport of chemical species along a concentration gradient, within a solid, liquid or gaseous phase.
<b>Discrete items</b>	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.
<b>Discretisation</b>	Is the process of breaking down a large model into discrete sections or compartments that are individually represented within a model.
<b>Disposal</b>	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.
<b>Dose constraint</b>	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 $0.3 \text{ mSv y}^{-1}$ when determining applications for discharge authorisations from a single new source, and a dose

constraint value of  $0.5 \text{ mSv y}^{-1}$  for a complete site (which may include several sources with more than one operator).

<b>Dose rates</b>	The radiation dose (dosage) absorbed per unit of time.
<b>Effective dose</b>	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).
<b>Effluent</b>	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.
<b>Eh</b>	Redox potential, which is a measure of the tendency of a chemical species to acquire electrons and thereby be reduced.
<b>Elicitation</b>	A structured process in which a group of experts are brought together to derive logical theoretical outcomes or to solve problems.
<b>Emplacement</b>	The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.
<b>Emplacement strategy</b>	A strategy to control the locations in which certain waste streams and waste consignments are emplaced in the vaults. For example, not placing certain waste in the upper levels of stacks in the vaults in order to reduce the probability of inadvertent human intrusion into such waste. An emplacement strategy may be necessary to meet dose constraints and dose guidance levels, or it might be an optimisation measure to minimise the environmental impact of disposals to the LLWR.
<b>Engineered barrier</b>	A barrier that is designed to protect from human intrusion into disposed waste and minimise the release of contaminants, both radiological and non-radiological, from the disposal facility, consequently minimising the dose to humans and non-human biota.
<b>Engineering performance assessment (EPA)</b>	An evaluation of engineered system degradation and associated failure mechanisms.
<b>Environmental permit</b>	A permit issued under the Environmental Permitting (England and Wales) Regulations 2010.
<b>Environmental safety</b>	The safety of people and the environment both at the time of disposal and in the future.
<b>Environmental safety case (ESC)</b>	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.
<b>Exposure pathway</b>	An exposure pathway refers to the way a person can come into contact with a hazardous substance. There are three basic exposure pathways: inhalation, ingestion, or direct

contact. A person can also receive dose from radioactive substances via external irradiation.

**Extended disposal area (EDA)**

An extended area of the repository, beyond but including the Reference Disposal Area, which is considered in the 2011 ESC to be sufficient to dispose of all waste requiring vault disposal in the United Kingdom Radioactive Waste Inventory.

**Features, events and processes (FEPs)**

Any factors that may influence the disposal system.

**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.

**Gamma radiation**

Electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous.

**Geosphere**

The geological formations and subsurface environment through which radionuclides may migrate.

**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.

**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.

**Inorganic**

Not having the structure or characteristics of living organisms; not organic.

**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 two 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.

<b>Isotopic ratios</b>	The relative abundance of different isotopes in a given sample.
<b>Issue assessment form (IAF)</b>	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.
<b>Issue resolution form (IRF)</b>	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.
<b>Leachate</b>	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.
<b>Lifetime Plan</b>	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.
<b>Low level waste (LLW)</b>	In government policy, low level waste is defined as 'radioactive waste having a radioactive content not exceeding four gigabecquerels per tonne (GBq te <sup>-1</sup> ) of alpha or 12 GBq te <sup>-1</sup> 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.
<b>Monitoring</b>	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.
<b>Near field</b>	In the context of the assessments in support of the LLWR ESC, the near field consists of the waste and engineered barriers.
<b>New build programme</b>	The proposed development of a number of new nuclear power reactors within the UK.
<b>Operational environmental safety case</b>	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.
<b>Optimisation</b>	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.

<b>Organic</b>	A class of chemical compounds that include carbon within their structure.
<b>Oxidation</b>	A chemical reaction that involves the loss of electrons or an increase in the oxidation state of a molecule, atom or ion.
<b>Pathway</b>	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.
<b>Period of authorisation</b>	The period of time during which disposals are taking place and any period afterwards while the site is under active institutional control.
<b>pH</b>	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.
<b>Pore water</b>	The water filling the spaces between grains of sediment.
<b>Post-closure safety case</b>	The safety case presented as part of the ESC that covers the time after the end of the period of authorisation.
<b>Potentially exposed groups (PEGs)</b>	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.
<b>Primary waste</b>	This is the waste disposed to the LLW as it has originated from the consigner without undergoing any further treatment.
<b>Profiling material</b>	The material put in place over the disposed waste prior to placement of the engineered cap to induce settlement and compaction of the waste (surcharging), ensure that any further settlement or compaction will not affect the functionality of the cap and create the final profile of the cap.
<b>Pucks</b>	A term used to describe the product of high-force LLW compaction, the product being a smaller volume of compacted waste.
<b>Putrescible</b>	Liable to decay – generally used to describe an organic material that will become rotten.
<b>Radioactive decay</b>	Spontaneous disintegration of a radionuclide accompanied by the emission of ionising radiation in the form of alpha or beta particles or gamma rays.
<b>Radioactivity</b>	The emission of alpha particles, beta particles, neutrons and gamma or x-radiation from the transformation of an atomic nucleus.
<b>Radionuclide</b>	An unstable form of an element that undergoes radioactive decay.

<b>Radionuclide fingerprint</b>	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.
<b>RECALL interviews</b>	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.
<b>Receptor</b>	Something that could be adversely affected by a contaminant, such as people, an ecological system, property or water body.
<b>Reducing conditions</b>	Conditions that promote the gain of electrons or a decrease in the oxidation state of a molecule, atom or ion.
<b>Reference case</b>	The baseline set of assumptions about the disposal facility and its evolution with time that is used in the calculations of dose and risk.
<b>Reference design</b>	The engineering design arrived at through optimisation studies within the 2011 ESC. It is used as the basis for detailed assessments of facility performance and radiological and non-radiological impacts within the 2011 ESC.
<b>Reference disposal area (RDA)</b>	The disposal area including the trenches and Vaults 8 to 14.
<b>Regulatory issue (RI)</b>	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.
<b>Regulatory observation (RO)</b>	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).
<b>Retardation</b>	A measure of the reduction in solute velocity relative to the velocity of the flowing groundwater caused by processes such as adsorption.
<b>Retrievability</b>	A characteristic of the design of the waste package and/or the disposal facility that facilitates recovery of waste after emplacement.
<b>Risk guidance level</b>	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.

<b>Scenario</b>	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.
<b>Secondary waste</b>	Waste produced as a result of the primary waste form undergoing a secondary treatment process. An examples of secondary waste is ash from combustion.
<b>Shielding</b>	Material placed in front or around a radioactive material to reduce the effects of its radiation.
<b>Sievert (Sv)</b>	The International System of Units (SI) unit of effective dose, obtained by weighting the equivalent dose in each tissue in the body with ICRP-recommended tissue-weighting factors, and summing over all tissues. Because the Sievert is a large unit, effective dose is commonly expressed in milli-Sieverts (mSv) – that is, one thousandth of one Sievert, and micro-Sievert (µSv) – that is, one thousandth of one milli-Sievert.
<b>Site Licence Company</b>	The legal entity (LLW Repository Ltd) that operates the LLWR on behalf of the Nuclear Decommissioning Authority (NDA).
<b>Source term</b>	Description of the characteristics of the waste inventory (for example radioactivity, chemical hazard and volume) used as a basis in assessments of environmental impacts.
<b>Specific activity</b>	Radioactivity per unit mass of a waste.
<b>Sub-bay</b>	A sub-division of the trenches at the LLWR, each sub-bay consisting of columns and rows approximately 5 m wide by 25 m long.
<b>Superplasticiser</b>	A chemical added to grout to increase its fluidity and thus enhance its ability to infiltrate voidage within waste packages.
<b>Surcharge</b>	The material added to the top of the waste prior to the engineered cap being placed over the trenches, to induce settlement in the waste materials and thus limit the extent of settlement that the engineered cap will be initially subjected to.
<b>Technical query (TQ)</b>	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.
<b>Trench</b>	A trench is an excavation in the ground into which loose waste was tumble tipped.
<b>Tumble tipping</b>	The process by which waste was emplaced within the historical trenches. It typically involved a truck driving to the edge of the trench and tipping the waste into the trench before being covered.
<b>UK Radioactive Waste Inventory (UKRWI)</b>	The UKRWI is provided by the Department of Energy and Climate Change (DECC) and the Nuclear Decommissioning

Authority (NDA). The inventory provides comprehensive and up-to-date information on radioactive waste in the United Kingdom. It provides a consistent reference source of information for government, its agencies, NDA, and others with a role or interest in the management of radioactive waste. The inventory is routinely updated and published in the public domain, currently on a 3 yearly cycle.

<b>Ullage</b>	The unfilled space at the top of a grouted ISO freight container, immediately below the lid.
<b>Uncertainty</b>	Lack of certainty. A state of limited knowledge that precludes an exact or complete description of past, present or future.
<b>Unsaturated</b>	A volume of material is unsaturated when some or all of the pore space is filled with air.
<b>Variant cases</b>	Alternative calculation cases that are defined to investigate the effect of uncertainty in FEPs on the risk and dose calculations.
<b>Vault</b>	A space constructed of reinforced concrete base slabs and walls where wastes are emplaced.
<b>Waste acceptance criteria (WAC)</b>	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.
<b>Waste Accountancy Template</b>	These are produced by NDA sites annually and are used to support the sites' Lifetime Plans. They consist of information on volumes, radionuclide content, materials composition and assumed disposition route.
<b>Waste Consignment Variation Form</b>	A form that customers complete when seeking agreement to vary a condition within LLW Repository Ltd's Waste Acceptance Criteria.
<b>Waste form</b>	The waste and its immediate packaging (for example grout and container) that is disposed of at the LLWR.
<b>Waste stream</b>	Waste streams are designated in the UKRWI to summarise waste or a collection of waste items at a particular site, usually in a particular facility or from particular processes or operations. A waste stream is often distinguishable by its radioactive content and, in many cases, also by its physical and chemical characteristics.
<b>Waste stream fingerprint</b>	The activity per unit mass for each radionuclide, which can be used to calculate the activity for a mass or volume of that waste stream.

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