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Review of LLW Repository Ltd's "Requirement 2" submission

Technical Review of Volume 4: Site Understanding

NWAT/LLWR/09/004 [Sector Code]

ea/br/e/std/v1

Contents

Introduction

1.1 Site history

1.1.1 The Low Level Waste Repository near Drigg, Cumbria (LLWR) is located six miles south of the Sellafield site in the northwest of England. Radioactive waste disposal began at the site in 1959 when the LLWR was managed by the United Kingdom Atomic Energy Authority (UKAEA). The LLWR site occupies around 100 hectares; waste disposal operations take place in the northern 40 hectares of the site. During the early period of disposal operations, solid low level radioactive waste (LLW) was tipped and buried in shallow, clay-lined trenches, a practice similar to that used now in the landfill industry. Between 1959 and 1995, approximately 800,000 m^3 of waste was disposed in seven trenches. These trenches are now covered by an interim earth cap, which incorporates a plastic membrane to minimise water ingress.

1.1.2 In 1986 the House of Commons Environment Committee published a report on radioactive waste (House of Commons, 1986). In response to the report's recommendations, the LLWR operator at the time, British Nuclear Fuels plc (BNFL), made major changes to disposal operations. Since 1988, wastes have been disposed of in containers emplaced in an engineered concrete vault (Vault 8). Typically, the waste is put into steel drums which are then compacted into 'pucks'. These pucks are packed into freight containers that conform to published standards of the international standards organisation ISO. The wastes in full containers are encapsulated in cement grout before being placed in the vault. Vault 8 has a total capacity of 200,000 m^3; at the time of writing it is nearly full. The current operator of the LLWR, LLW Repository Ltd, plans to build additional vaults to accept further waste, subject to receiving planning permission from Cumbria County Council.

1.2 Regulatory background

1.2.1 The Environment Agency of England and Wales (the Agency; also referred to as "we" and "us") is responsible for authorising disposal of radioactive waste under the amended Radioactive Substances Act 1993 (RSA 93). In accordance with government policy, we periodically review authorisations for the disposal of radioactive waste. When we review an authorisation, we consider a wide range of information, including our conclusions from reviews of the environmental safety cases (ESCs) produced by the operators of a disposal facility.

1.2.2 The Health and Safety Executive (HSE), through its Nuclear Installations Inspectorate (NII), regulates nuclear safety. It ensures that radioactive waste on nuclear licensed sites is managed, conditioned and stored safely. The NII also has regulatory responsibility for accident risk management.

1.2.3 In 1999, we started a review of the RSA 93 authorisation for the LLWR, which was then held by BNFL. At that time, however, BNFL had not updated the impact assessment carried out in the 1980s by the National Radiological Protection Board (NRPB, now part of the Health Protection Agency, HPA). Our review was therefore unable to assess the potential impact of the site from existing and future (predicted) disposals. Consequently, in January 2000 we changed (varied) the LLWR authorisation and required BNFL to provide information about the environmental safety of the LLWR during its operational lifetime (Operational Environmental Safety Case, OESC) and after its final closure (Post Closure Safety Case, PCSC). BNFL submitted these two ESCs in September 2002 (BNFL, 2002a and 2002b). Between 2002 and 2005 we carried out a detailed assessment of the safety cases (Environment Agency, 2005a) which raised a number of criticisms, many of which were formally recorded in Issue Assessment Forms (IAFs)[1].

1.2.4 Following the review of the 2002 ESCs, we reviewed the RSA 93 authorisation and in May 2006 granted a new one (Environment Agency, 2006a) to the operator, which by that time had become known as British Nuclear Group Sellafield Limited (BNGSL). In addition to the ESCs submitted by BNFL in 2002, this authorisation review also took account of the legislation and guidance in effect at the time (RSA 93, and the UK environment agencies' Guidance on Requirements for Authorisation (the GRA), Environment Agency *et al*., 1997). Our concerns regarding the safety cases presented in 2002 led us to authorise disposals only to Vault 8, and required the operator to deliver an updated ESC by May 2011.

1.2.5 The LLWR site is now owned by the Nuclear Decommissioning Authority (NDA) and is operated on behalf of the NDA by a Site Licence Company (SLC). The SLC was initially BNGSL, but the authorisation was transferred in 2007 to a new SLC, LLW Repository Ltd, with no major changes to the authorisation. This change in SLC paved the way for the NDA to open the operation of the site to competitive tender. In 2008 United Kingdom Nuclear Waste Management Ltd (UKNWM Ltd) was awarded a contract from the NDA to manage and operate the LLWR. Shares in the SLC were transferred to UKNWM Ltd on 1 April 2008 and the SLC continues to be known as LLW Repository Ltd.

1.2.6 LLW Repository Ltd is currently authorised to dispose of solid low-level radioactive waste in Vault 8 of the LLWR, and to discharge from the site gaseous and liquid effluents associated with the LLW disposal operations. LLW Repository Ltd has planning permission to construct Vault 9 at the site to *store* LLW, but does not have planning permission or authorisation to *dispose* of LLW to Vault 9.

1.2.7 In Schedule 9 of the current authorisation we set a number of legal requirements for the operator to carry out improvements or supply us with additional information by defined dates (e.g. reviews of best practice and establishing a research and development programme). This report relates to our review of LLW Repository Ltd's work to fulfil Schedule 9 Requirement 2 and their progress towards fulfilling Schedule 9 Requirement 6.

1.2.8 Requirement 2 states that the operator, by 1 May 2008, must "provide the Agency with a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events (e.g. coastal erosion and glaciation) and potential future human action."

1.2.9 In discussions with LLW Repository Ltd we agreed that, in addition to the specifics of Requirement 2, their response would also aim, as far as possible, to address the wider expectations expressed in our 2006 Decision Document (Environment Agency, 2006a), to:[2]

(a) demonstrate that best practice is being applied to keep the peak risks from the site as low as reasonably achievable (ALARA);
(b) substantiate a proposal for the radiological capacity of the site (the maximum amount of waste that could be disposed of while still maintaining the site's environmental safety).

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[1] Issue Assessment Forms (IAFs) are detailed records of concerns raised as part of the Environment Agency's review of BNFL's 2002 environmental safety cases. In a systematic manner they record issues that we expect the operator of the LLWR to address prior to submission of the next fully updated ESC in 2011.

[2] In section 4.6 of the Decision Document (Environment Agency, 2006b) we stated that "we will not authorise LLW disposals to the proposed Vault 9, until … BNGSL has provided us with adequate information to allow the radiological capacity of the site to be determined … and we will undertake a full review on the radiological capacity of the site and publish our findings." Later in the same section we stated that "we will not allow BNGSL to construct the final cap over the existing Vault 8 and trench disposals until BNGSL has provided us with the outcome of a wide-ranging risk management study … that demonstrates that future impacts will be As Low As Reasonably Achievable (ALARA)." The latter decision is clearly reflected in Requirement 2. We have interpreted the former decision also to be reflected in Requirement 2 as it comes from the same section of the Decision Document. We have confirmed to LLW Repository Ltd that this is the case and they have agreed to include their proposals on radiological capacity in their Requirement 2 submission.

1.2.10 Requirement 6 states that, by 1 May 2011, the operator must "update the Environmental Safety Case(s) for the site covering the period up to withdrawal of control and thereafter." This update should address our criticisms of the 2002 ESCs and supporting programmes (Environment Agency, 2005a, 2005b, 2006b). It should also take account of developments since the 2002 ESCs were produced, such as evolution of operating practices, additional information about the site, the design of the repository and the waste inventory, changes in ownership, and developments in government policy (Defra, 2007) and regulatory guidance (Environment Agency *et al.*, 2008).

1.2.11 Since 2006, we have had regular dialogue with LLW Repository Ltd about progress towards meeting the Schedule 9 requirements. We expected the information in LLW Repository Ltd's response to Requirement 2 would provide some indications of progress on the updating of the ESC, and so serve as a milestone for assessing progress towards the 2011 deadline for the submission of the ESC.

1.3 Objectives of our review

1.3.1 The main objectives of this review are to:

(a) assess whether the information supplied by LLW Repository Ltd represents a satisfactory response to Requirement 2;
(b) identify from the information supplied any immediate implications for the conditions of LLW Repository Ltd's authorisation;
(c) assess the information supplied against the new regulatory guidance (Environment Agency *et al.,* 2008[3]), and to provide additional guidance to LLW Repository Ltd on its programme to develop an ESC that appropriately addresses the requirements of the GRA;
(d) identify any additional assessment that we might need to carry out, such as independent R&D, model development, conduct of independent calculations, or examination of further documents, so that we can effectively and efficiently assess the ESC when it is provided.

1.4 LLW Repository Ltd's submission

1.4.1 On 1 May 2008, LLWR Repository Ltd delivered to us five volumes setting out its response to Requirement 2:

i. Volume 1 (LLW Repository Ltd, 2008a) summarises the submission and directly addresses the issues raised in Requirement 2;
ii. Volume 2 (LLW Repository Ltd, 2008b) summarises the "comprehensive review of options for reducing the peak risks from deposit of solid waste on the site";
iii. Volume 3 (LLW Repository Ltd, 2008c) summarises developments in characterising the inventory and near field processes;
iv. Volume 4 (LLW Repository Ltd, 2008d) summarises developments in site understanding (including geology, hydrogeology and coastal evolution);
v. Volume 5 (LLW Repository Ltd, 2008e) summarises updates (since the 2002 ESCs) to LLW Repository Ltd's assessment of the future performance of the facility.

1.4.2 These five volumes refer to a large number of supporting documents that provide details of the analyses, assessments and evidence that underpin the arguments presented in the top level volumes. In our assessment of LLWR Repository Ltd's submission we have also

[3] A consultation draft of the GRA for near surface disposal was issued in May 2008 (Environment Agency *et al.,* 2008), and a final version (Environment Agency *et al.,* 2009) in February 2009. In conducting this review we had access to the consultation draft, and initial indications of modifications likely to be made in finalising the GRA for near surface disposal. The final version was published as we were finalising our documentation of this review, and so was not explicitly taken into account. However, we do not believe that any differences between the consultation draft and the final version would significantly alter any of our conclusions or recommendations.

reviewed the supporting documentation to the extent we considered necessary for us to establish the soundness of the submission.

1.5 Our review

1.5.1 Our review considers LLW Repository Ltd's submission primarily in relation to:

(a) Schedule 9 Requirement 2;
(b) the April 2008 consultation draft of the environment agencies' Guidance on Requirements for Authorisation for near surface disposal, as an indication of progress towards meeting Schedule 9 Requirement 6; and
(c) the IAFs from the review groups participating in our review of the 2002 ESCs.

This report and our four other main review reports (Environment Agency, 2009a–d) present our findings in relation to Requirement 2, the GRA/Requirement 6, and any general or significant observations arising from our consideration of the IAFs. Our full review of the submission against the IAFs will be reported separately to LLW Repository Ltd as part of our continuing dialogue leading up to the delivery of the full ESC due in 2011.

1.5.2 We report here on our technical review of LLW Repository Ltd's response to the technical authorisation requirement we set out in the RSA 93 authorisation granted to the LLWR operator in 2006. This does not constitute a review of LLW Repository Ltd's authorisation, although it will be taken into account in the periodic review of the authorisation, which is due to be completed in early 2009. This review may also provide input into future periodic reviews.

1.5.3 We have aimed in our review to identify all significant issues arising from the Requirement 2 submission and supporting documents. Where we do not comment on a particular point in the submission or accompanying documentation, it is unlikely (based upon the information presented to us at this stage) that we would raise that point as an issue in the future (particularly in our review of the full ESC). However, this cannot be taken as an absolute guarantee; we reserve the right to revisit any issues that we think warrant attention at any time in the future.

1.5.4 Where we have made recommendations to LLW Repository Ltd in this and the four other main review reports, we have classified them to assist in the prioritisation of action:

(a) **Category A**
Relatively major issues for which the appropriate course of action is not immediately obvious. For these issues, we expect LLW Repository Ltd to provide substantial additional information, evidence or analysis in the full ESC. We also expect LLW Repository Ltd to report to us on their progress between now and delivery of the ESC. Such reporting might, for example, include detailed plans of action, descriptions of proposed approaches, models or data, or results from interim or provisional analyses.
(b) **Category B**
Relatively major issues for which it is fairly clear what needs to be done. For these issues, we expect LLW Repository Ltd to provide substantial additional information, evidence or analysis in the full ESC. We will keep these issues under a degree of review via the regular dialogue between ourselves and LLW Repository Ltd and we will provide further guidance if requested. However, we will not require LLW Repository Ltd to report formally on progress.
(c) **Category C**
Issues for which LLW Repository Ltd will need to provide some additional information, evidence or analysis in the full ESC, and report some or all of this to us between now and delivery of the ESC. Generally, we estimate the effort needed to address Category C recommendations will be substantially less than for Category A.
(d) **Category D**
Issues for which LLW Repository Ltd will need to provide some additional information, evidence or analysis in the full ESC, without the need for formal reports on progress.

Generally, we estimate the effort needed to address these points will be substantially less than for Category B.

Where our recommendations or other observations are not assigned to any of the above categories, we do not expect or require a specific response from LLW Repository Ltd. Nevertheless, LLW Repository Ltd may wish to consider these points as suggestions because they may, individually or collectively, affect our general confidence in the ESC or the ease with which we can review it. For example, individual typographical errors in reports may be considered trivial, but if persistent or present in large numbers, they could affect our confidence in the quality controls applied by LLW Repository Ltd.

1.5.5 We recognise that some of the issues raised in our review may be at least partly addressed in the updated and expanded Safety Case Approach document that LLW Repository Ltd produced at the end of 2008 (Baker *et al.,* 2008), but we have not included consideration of the Approach document in this review.

1.5.6 Our review mirrors the structure of LLW Repository's submission. Four separate technical review documents address Volumes 2–5 of the submission (and the supporting documentation), and this overarching summary review document provides specific comments on any aspects of Volume 1 not covered elsewhere and presents our overall assessment of the submission.

1.5.7 This technical review document addresses Volume 4: Site understanding.

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1 Review of Volume 4 and key supporting documents

2.0.1 The review comments provided here in relation to Volume 4 relate largely to the geological and hydrogeological information provided. Only some brief observations on the analysis of site evolution are presented here. A more detailed review of the analysis of site evolution is documented elsewhere (Environment Agency, 2009a; Cooper, 2008).

2.0.2 LLW Repository Ltd state that the material presented in Volume 4 describes their *"understanding of the LLWR site, including the geology and the hydrogeology and various impacts associated with climate change and coastal erosion"* and further states the *"primary aim of Volume 4 is to provide a better understanding of potential pathways for exposure from both radiological and non-radiological contamination."*

2.0.3 Relevant requirements from the GRA (Environment Agency *et al.,* 2008) are presented below.

Requirement R12: Site investigation

6.4.4 ***The developer/operator of a disposal facility for solid radioactive waste should carry out a programme of site investigation and site characterisation to provide information for the environmental safety case and to support facility design and construction.***

6.4.5 The developer/operator should establish an iterative approach to site investigation that uses results from site characterisation, modelling studies, design and construction to guide investigations. Each phase of site investigation should be presented as part of a structured forward programme.

6.4.6 The developer/operator will need to show that the geological environment is characterised, understood and can be analysed to the extent necessary to support the environmental safety case. This will involve considering, for example, the lithology, the stratigraphy, the geochemistry, the local and regional hydrogeology, and the resource potential of the area. The developer/operator will also need to assess the potential for, and effects of, dynamic processes such as seismic events and ground subsidence.

6.4.7 The developer/operator should show that the physico-chemical and geochemical characteristics of the geological environment, combined with the engineered barrier systems of the facility, will inhibit the migration of radionuclides.

6.4.8 The developer/operator will need to show that the biosphere is characterised, understood and capable of analysis to the extent necessary to support the environmental safety case. This may involve consideration of, for example, topography, soils, surface water systems, flora and fauna distributions and human settlement patterns and activities. The investigation and characterisation of the biosphere should be sufficiently comprehensive to support calculations of dose during the period of authorisation and should be proportionate to the assumptions made in the environmental safety case for calculating risks after the period of authorisation.

6.4.9 The developer/operator should show that the geological, hydrogeological and other characteristics of the region and the site under present and reasonably foreseeable future conditions will allow the environmental safety case for the facility to be made. This demonstration should include considering features and properties of the site related to the release and transport of radionuclides in the gas phase.

6.4.10 The developer/operator should identify the presence of any actually or potentially valuable resources near the site and make an assessment of the extent to which the site and its surroundings might be disturbed as a result. The developer/operator will need to consider the implications for the integrity of the disposal system (see Requirement R8).

6.4.11 Knowledge of the site characteristics is expected to increase progressively through the site investigation and the facility development phases. We shall be proportionate in our assessment of the adequacy of the site characterisation information presented in the context of an evolving environmental safety case.

Requirement R15: Monitoring

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

6.4.32 The developer/operator should establish a reasoned approach to, and a programme for, monitoring the site and facility. The monitoring approach must not compromise the environmental safety of the facility.

6.4.33 In order to provide a baseline for monitoring at later stages, the developer/operator will need to carry out monitoring during the investigation and pre-construction stages. The same measurements may form part of the site investigation programme (see Requirement R12 above). They should include measurements of pre-existing radioactivity in appropriate media, together with geological, physical and chemical parameters which are relevant to environmental safety and which might change as a result of construction and waste emplacement (for example groundwater properties such as pressures, flows and chemical composition).

6.4.34 During the period of authorisation, radiological monitoring and assessment will be needed to provide evidence of compliance with authorised discharge limits and assurance of radiological protection of members of the public. In addition, during the construction stage and the period of authorisation, such non-radiological parameters as are needed to confirm understanding of the effects that construction, operation and closure of the facility have on the characteristics of the site will need to be monitored. In particular, the developer/operator will need to demonstrate that the changes in, and evolution of, the parameters monitored are consistent with the environmental safety case.

6.4.35 We shall need to be satisfied that the developer/operator has carried out appropriate investigation and monitoring during the construction stage and period of authorisation to establish the characteristics of the site; the behaviour of the disposal system; and the extent of disturbance caused by intrusive site investigation procedures and by construction, operation and closure of the facility.

6.4.36 In accordance with Principle 5, that unreasonable reliance shall not be placed on human action to protect people and the environment, assurance of environmental safety must not depend on monitoring or surveillance after the declared end of the period of authorisation. Subsequent monitoring is not ruled out providing it does not produce an unacceptable effect on the environmental safety case, but it will be for public re-assurance.

2.1 Document presentation

2.1.1 The Executive Summary of Volume 4 seems unbalanced. It presents information that favours LLW Repository Ltd’s position without acknowledging the relatively limited scope of the work reported and the inherent uncertainties and limitations associated with the work. For example, the Executive Summary barely mentions the uncertainties that are inherent in the interpretation and analyses presented in the main text, aside from a single comment on the quality of the calibration of the current site-scale groundwater flow model. Similarly, no mention is made of the current or anticipated work programmes that are required to resolve various outstanding issues and reduce remaining uncertainties. The Executive Summary is inclined to present a single position in support of one side of an argument in several other areas. For example, it states that the hydrogeological interpretation has been improved because *"the model now takes into account the wider regional context"* but it is not clear how this assertion is consistent with the lack of agreement that currently exists between the regional and site-scale groundwater flow models (see Section 2.3.16 in this report).

2.1.2 The material in Volume 4 is presented in four main sections – Geology, Hydrogeology, Site Evolution, and Hydrogeological Modelling – arranged in that order. This structure has resulted in the spread of information relating the hydrogeological understanding of the site across three different sections (Hydrogeology, Site Evolution and Hydrogeological Modelling). We would have found it more helpful if this hydrogeological understanding had been presented in a single section; this would have provided a more coherent and consistent summary of the interpretation and consequences of hydrogeological understanding in terms of safety arguments. We also see merit in revising the sequence in which the aspects of site understanding are presented so that the evolution of the site is addressed before its hydrogeology (thus keeping the sections called Hydrology and Hydrogeological Modelling together). By presenting the information in this sequence the discussion of site evolution could also be framed in terms of the 'boundary conditions' that it provides to the hydrogeological analyses (e.g. topography, climate, sea-level). We note that our comments on the geological and hydrogeological interpretations presented in the 2002 PCSC (Environment Agency, 2005a) included criticisms of the way they were presented.

2.1.3 Given the importance of the site's evolution to LLW Repository Ltd's appraisal of the risks to (and from) the LLWR, it is surprising that relatively little information is provided in Volume 4 on the methodology used to develop the three main evolution pathways that it covers. We recognise that the decision about how much detail to include in such a high level document is a matter of judgement, but the current description of the process for developing scenarios of changes to the landscape is little more than a paragraph or two, with no description of the uncertainties and the expert judgements made in developing the evolution pathways. The documentation describing the development of the evolution pathways (Thorne and Kane, 2007) is itself both complex and lengthy, but its conclusions are crucial to the ESC; we therefore see significant benefits in Volume 4 providing a little more information on the key points of this documentation.

2.1.4 Similarly, the information in Section 5 of Volume 4 – a presentation of the work undertaken on hydrogeological modelling and the transfer of data from the hydrogeological model to the safety assessment – is comparatively brief. The description of the work is unclear and lacks detail so the reader must review the supporting documents to obtain a clearer view of the work undertaken. We suspect that this section of Volume 4 was produced over a much shorter timescale than other sections. We acknowledge the particular time pressures to meet the deadline for responding to Requirement 2, but for the full ESC we expect LLW Repository Ltd to set project data freezes and internal milestones so that sufficient time is available to produce summary documentation with an appropriate and balanced content, which is quality assured to an acceptable standard.

2.1.5 It is apparent from differences in terminology and writing styles that Volume 4 has been compiled from underlying source material written by different authors. We have also noted several errors throughout the document (e.g. missing items from figure legends, typographical errors, incorrect formatting, incorrect referencing). In our opinion the document would have benefited from further review prior to its finalisation. The text is complemented with appropriate figures, but the impact of some of the information is lost in the electronic version of the document, e.g. some figures were apparently designed to fit a page size other than A4 in hard copy, but these do not come out well in the electronic version. We recognise that the presentation of geological and hydrogeological information can be especially challenging, but we suggest that solutions to these difficulties are investigated, especially if electronic delivery of reports is to become the default. These weaknesses in quality control detract from the overall quality of Volume 4 and are further discussed below where appropriate.

2.1.6 Volume 4 does not mention any plans for future work to address limitations in the current level of understanding and to develop further the site understanding in advance of the full ESC due in 2011. Given the limitations acknowledged by LLW Repository Ltd and our observations in this review, we expect LLW Repository Ltd to set out and commit to a forward-looking strategy with clearly defined objectives, so that we may be assured that its site understanding will be adequate to support the full ESC due in 2011. Based on this review we are concerned about LLW Repository Ltd's lack of a defined approach to assess the impacts of uncertainty on its analyses. We expect LLW Repository Ltd to develop a clear plan for the treatment of uncertainty in the full ESC.

2.1.7 The introduction of Volume 4 is clear that assessment covers the post-closure period. While this timescale is consistent with the wording of Requirement 2, the development of evolutionary models of site understanding requires that the information used for the post-closure period is consistent both with the observed behaviour of the system and its anticipated behaviour during the remainder of the operational period. In our view, Volume 4 does not provide or justify a clear and consistent position on the period to which the conceptual and numerical models of hydrogeology are considered to relate. It is also unclear how the timescales covered by the hydrogeological modelling and reported in Volume 4 meet the timescales and time-dependent needs of near field and safety assessment calculations.

2.1.8 Generally, the level of cross-referencing in Volume 4 to relevant supporting material seems overly complex. For the sections on geological understanding, the cross-referencing is adequate. However, the main documentation of the geological reinterpretation consists of four documents, but three of these are 'updates'. The presentation and referencing of these documents could therefore be made simpler. As mentioned previously, it would be useful to expand the section on site evolution in Volume 4 to give a fuller picture of the basis for the assumptions made in the performance update.

2.1.9 Numerous supporting references are also cited in the description of the development of the conceptual model for the hydrogeology of the site and the numerical analysis. Various sections of Volume 4 state the following as the key references related to hydrogeology:

(a) Section 1 suggests Arthur *et al*. (2008a), Arthur *et al*. (2008b) and Sears (2007).
(b) Section 3 suggests it is "supported" by Hunter *et al*. (2007), BNFL (2002a), Towler *et al*. (2006) and Ruddick and Foster (2007) and "informed" by BNFL (2002a) and subsequent revisions and updates presented in Towler *et al*. (2007) and Towler and McGarry (2007) as well as the previously cited Sears (2007). Citations to other references are made in relation to other key aspects.
(c) Section 5 notes Bond (2007) in addition to Arthur *et al*. (2008a), Arthur *et al*. (2008b) and Towler and McGarry (2007) and also flags important related work supporting Vault 9 which is yet to be incorporated.

The audit trail in this area is therefore particularly complex, and we were obliged to ask LLW Repository Ltd for further clarification during the course of our dialogue. A simpler structure for the supporting documentation and clearer information would have made the presentation of the submission clearer, enabled more consistent discussion and aided the review process. We note that Sears (2007) contains a useful summary that could have been used to develop a précis for Volume 4. Improving this aspect of reporting could significantly simplify the process of reviewing a document such as Volume 4. Comments on some of the key supporting references can be found in Appendix 1.

2.1.10 A further consequence of this complicated audit trail is that we found several errors and inconsistencies relating to the referencing of supporting documents, including the use of incorrect dates and report numbers (e.g. Hunter *et al*., 2007) and duplicate references with different years (e.g. Towler *et al*. (2006) is duplicated in an earlier reference to an identical report). It may also be useful to improve the referencing by including details of report versions and dates where this information is available.

2.1.11 One of the key hydrogeological references, Arthur *et al*. (2008a), was listed as "In preparation" in Volume 4. During our review of the Requirement 2 submission we requested a copy of this reference; on receipt we discovered that the report had a different lead author. This inevitably raised some questions about possible inconsistency between the information referred to in Volume 4 and the final content of the supporting report.

2.1.12 The adequacy of the referenced content to support the stated data, analysis, safety arguments and conclusions is considered below.

2.2 Geology

2.2.1 Volume 4 indicates that the main focus of the geological analyses undertaken for the Requirement 2 submission is to underpin more fully the conceptual model of the site's hydrogeology through the development of a three-dimensional geological model. We criticised the quality of the link between these models in our review of the 2002 PCSC (Environment Agency, 2005a), so we have focused on this area in our review of Volume 4.

Technical quality

2.2.2 Descriptions of the geological analysis in Volume 4 necessarily use a relatively large amount of geological terminology. However, in several respects the presentation of geological information is inconsistent and could confuse or mislead readers. For example, the sediments underlying the Quaternary deposits are variously referred to as "bedrock" (e.g. Sections 2.1, 2.4, Figure 2.3, Appendix of Volume 4) "basement" (e.g. Section 2.2), "rockhead" (Figure 5.1) and "sandstone" (Figure 3.1). The sediments are described variously as "sedimentary breccias of Permian age overlain by sandstones of the Triassic Sherwood Sandstone Group", "St. Bees Shale, St. Bees Evaporites and Brockram Formations", and "Ormskirk Sandstone Formation". In Section 3.1 of Volume 4 the most important stratum beneath the Quaternary deposits is suggested to be both the Sherwood Sandstone and Ormskirk Sandstone. Given the efforts taken to provide such consistency for the Quaternary deposits, it is disappointing that similar effort was not made in relation to the solid geology. It would have been useful to present initially a concise summary of the underlying strata, perhaps by expanding the text describing Figures 2.2 or 2.4, and then to use consistent terminology thereafter to avoid confusion. It may be helpful to include a glossary that provides consistent and clear definitions and descriptions of technical terms used within reports.

2.2.3 Bond (2006) noted several drawbacks to the event stratigraphy that was adopted in the 2002 PCSC and used to develop a geological conceptual model. For example, it does not focus on the distribution of material types, which is important for developing a hydrogeological model. Bond (2006) therefore recommended that the geological interpretation should be reviewed. However, Volume 4 states that the main objective of the review of the geological interpretation was *"to enable LLWR sitescale lithofacies packages to be related to the regionally-defined and simplified lithofacies units, and to provide a simplified geological interpretation that would be more suitable for its intended end uses, including the provision of the basis of an updated hydrogeological interpretation and support to the engineering design."* This is an extremely focused and prescriptive objective; it tells us nothing about the how the methodology for reviewing the interpretation was selected – effectively Volume 4 appears to skip over this selection stage. A more appropriate objective would have been to review the limitations of the present geological interpretation and revise it to fit better with its intended purposes, whilst documenting the reasoning behind the chosen approach.

2.2.4 Hunter *et al*. (2007) refer to a workshop held at the outset of the review of the geological interpretation to *"identify the most appropriate approach to the reinterpretation; ensure that sufficient justification exists as to why the approach used to the reinterpretation presented in this report is appropriate, and therefore why stakeholders could have confidence in the resultant geological interpretation."* This objective is more in line with our expectations.

2.2.5 We requested a copy of the workshop report and were provided with Smith (2006), a memorandum by Nexia Solutions addressed to the "LLWR Geological Reappraisal Team". This document does not state that it is a record of a workshop nor does it provide details of the various options considered for the review of the geological interpretation, although it does refer to a "review process". Instead it contains a brief summary of some limitations of the 2002 PCSC geological interpretation (BNFL, 2002b) and some supporting discussion on the new approach that appears to have been established by the "review process". The term 'lithofacies' is not mentioned in the note itself although it clearly underlies the discussion. Smith (2006) mentions a "peer review process" which may refer to that of the 2002 PCSC but does not explicitly draw on its findings in developing the approach to review the geological interpretation. Similarly no reference can be found to our review of the 2002 PCSC and its findings and recommendations in relation to the geological interpretation. Therefore, based on the information received, we do not see evidence that a structured and logical process was taken to identify the most appropriate approach to review the geological interpretation. It also appears that the reporting of the development of the approach is either insufficient or inconsistent within Volume 4 and the supporting documentation.

2.2.6 The presentation of the lithofacies-based approach for the review of the geological interpretation within Volume 4 is confusing. The first mention of 'lithofacies' is made in stating the objectives of the review of the geological interpretation, but the term is not defined until later. The first mention of the term is in reference to lithofacies units, but the term is thereafter encountered within the report mainly in terms of lithofacies packages. We recognise that the use of a lithofacies-based approach over one based around 'event stratigraphy' may represent an advance in geological understanding; we also note that several of the units defined in the 2002 PCSC are readily mappable onto the lithofacies units that have been identified (Figure 2.5 in Volume 4). However, it is not apparent to us whether a lithofacies-based approach can improve the identification, discretisation and characterisation of the key strata or lithological horizons which may ultimately control groundwater flow and radionuclide migration. It is difficult for us to assess the overall adequacy of the lithofacies-based approach without such factors being acknowledged and discussed at the outset.

2.2.7 It is encouraging to see that in several places the review of the geological interpretation refers to the requirements of the hydrogeological interpretation. However, such links must be made carefully so that the geological interpretation does not make hydrogeological judgments or assumptions that are not appropriate. For example, in Volume 4 it is stated that *"number of lithofacies units resulting from this analysis provides a practicable basis for hydrogeological modelling."* It is not clear how such a judgement can be made, given that this is the first time that a hydrogeological interpretation based on a lithofacies-based geology has been attempted for the LLWR. There also seems to be an assumption within the geological analysis that the Quaternary deposits are the 'most important' in understanding the hydrogeological performance of the LLWR geosphere, whereas it is probably more appropriate to say that they are the 'most challenging' aspect. This bias towards the Quaternary geology is further enhanced by the focus of the review of the geological interpretation. These assumptions are not always reflected in the subsequent hydrogeological analysis.

2.2.8 The database used in the review of the geological interpretation is described in Hunter *et al*. (2007), Smith (2007a) and Smith (2008). We welcome the incorporation into the databases of additional data acquired or identified since the 2002 PCSC . However, our confidence in the new geological interpretation could have been increased by providing information on how data from new boreholes drilled on the LLWR site has addressed our previous comments on the relatively sparse amounts of data on the deeper Quaternary deposits and underlying solid geological succession (Environment Agency, 2005a).

2.2.9 No mention is made in the supporting documentation of whether any quality assurance checks were made on the data in the Drigg Site Characterisation Programme (DSCP) database before it was used in the review of the geological interpretation. Other reviews (i.e. Bond, 2006) have identified errors in data in the DSCP database. Hunter *et al*. (2007) state that the DSCP database will *"contain an unknown, but small percentage of transcription errors"*. However, Hunter *et al*. (2007) does not justify why the unknown errors are assumed to be small in number, nor why a small number of errors could not be significant to an interpretation if the uncertainties related to key data.

2.2.10 Volume 4 makes only limited reference to the three-dimensional geological models at the scale of the site and the region that have been developed elsewhere (e.g. Smith, 2007a); this omission is odd, given that the Executive Summary refers to the importance of these models to the hydrogeological analysis.

Model development

2.2.11 In our view, a flow diagram or description showing all the stages and sequences of events in the review of the geological interpretation would have helped our understanding considerably. It is not clear whether the geological models were specifically produced to assist the interpretation exercise (and so were part of an iterative loop) or whether they represent an output from the interpretation exercise. Hunter *et al*. (2007) indicate that site-scale and regional-scale lithofacies models were developed in parallel, but provide no discussion to justify this approach. It is also unclear whether field visits took place before the lithofacies packages had been developed or whether they were part of the development of the site-scale lithofacies packages.

2.2.12 Although the approach to geological modelling and the results are described relatively clearly in Hunter *et al*. (2007), the subsequent release of 'updates' (Smith, 2007b; 2008) is confusing and complicates the audit trail. A single supporting document on the review of the geological interpretation that incorporated the relevant aspects of Hunter *et al*. (2007), Smith (2007b) and Smith (2008) could have made the audit trail[4] much more transparent.

2.2.13 The geological modelling is described in more detail in Smith (2007a; 2007b; 2008). In the Phase I work (Smith, 2007a) geological models were developed separately at the regional and site scales. The site-scale modelling used 3DAnalyst (a module of ArcGIS) whereas the regional scale modelling used RockWorks. Initially the documentation indicates that there was insufficient site-scale data for the "complex modelling processes" performed by RockWorks; later Volume 4 states that RockWorks is better at processing large sets of data. The exact reasons for the selection of different software for each scale therefore is not entirely clear. The two models were also combined as part of a "validation exercise" using a third piece of software, ArcScene (previously described as a visualisation package). In the Phase II work (Smith, 2007b; 2008) a single model is developed using RockWorks, even though it had previously been deemed unsuitable for use at a site scale.

2.2.14 We welcome the graphical presentation of the regional and LLWR lithofacies packages in Figures 2.4 and 2.5 in Volume 4. As noted previously, a similarly concise and consistent approach to reporting the solid geology would improve the presentation of Volume 4. There are also some unexplained differences in the figures that warrant further investigation, for example:

(a) Why are LLWR Site Lithofacies Packages LP2 and LP3 undivided in Figure 2.5?
(b) What is the justification for both the upper and lower silt sands within LLWR Site Lithofacies Package 5 being designated as LP6?

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[4] For example, Smith (2008) is not referenced in either the development of the hydrogeological conceptual model (Sears, 2007) or the site-scale groundwater flow model (Henderson *et al*., 2008).

(c) Why has Greencroft Till Mbr been included in Figure 2.4?[5].

2.2.15 A brief summary of the site-scale lithofacies packages is given in Volume 4, but it refers to the hydrogeological interpretation (Sears, 2007) rather than to the geological interpretation in which the packages are defined (Hunter *et al*, 2007). The logic for this reference seems to be that the discussion of the packages in Section 7.4 of Hunter *et al* (2007) is rather long and is not summarised, whereas Sears (2007) gives brief summaries. However, use of the summaries provided in Sears (2007) may have introduced an additional source of confusion.

Treatment of uncertainty

2.2.16 As noted previously, Volume 4 provides very little information on the identification of sources of uncertainty and appraisal of their potential impacts on the analyses. The concluding remarks describe the development of a single geological concept for the site as a positive outcome. It appears that no thought has therefore been given to investigating other potential conceptual models that are also consistent with the available datasets and their uncertainties. Indeed, we note that the single geological concept is presented in Volume 4 as being a direct result of an improved understanding of the site.

2.2.17 We expect LLW Repository Ltd to present and justify clearly their approach to identifying and assessing all relevant sources of uncertainty that have the potential to affect the geological understanding of the LLWR and any associated areas of the ESC that would be affected by such uncertainties.

2.3 Hydrogeology

2.3.1 The main focus of our review of the hydrogeological analyses reported in Volume 4 was to examine the underpinning evidence and supporting documentation for the statements made regarding the hydrogeological interpretation of the site. We also examined the link between the hydrogeological conceptual model and other related parts of the Requirement 2 submission, such as the Engineering Performance Assessment and the performance update.

Technical quality

2.3.2 The clarity of LLW Repository Ltd's description of the hydrogeological interpretation and understanding could be significantly improved by a diagram or a brief description to show the overall process that was followed to develop the models from the supporting analyses. This clarification would be particularly helpful given the sub-division of the hydrogeological analysis into separate sections located before and after the section in Volume 4 on site evolution. For example, there is generally insufficient distinction between the processes of conceptual model development and the results of model development.

2.3.3 The initial descriptions of the hydrogeological setting are inconsistent in their treatment of the relative importance of groundwater flow through the Quaternary deposits and underlying strata. Section 2.3 of Volume 4 states that the hydrogeological properties of the Quaternary deposits are most important and it is suggested that the relatively shallow groundwater flows through horizons are of primary interest. In Section 3.1 it is stated, to the contrary, that most of the groundwater flow occurs within the Sherwood Sandstone Group which lies below the Quaternary deposits. While this statement may have been intended to refer to regional groundwater flows, which include some flows in the Quaternary, it illustrates the potential for confusion at the outset.

2.3.4 Similar ambiguities also appear in some of the modelling studies. For example, in the development of the saline interface model, flow through the Quaternary is simplified; this decision is justified on the basis that the flow is not important to the development of the

[5] Its provenance in the figure is explained in Smith (2007a).

saline interface (Bond, 2007). However, particle tracking simulations through the Quaternary sediments are used to justify discharge locations; they are subsequently interpreted and used by Sears (2007) in the development of conceptual and numerical models.

2.3.5 As noted previously, Volume 4 does not present clearly the timeframes over which the datasets used have been collected and over which the interpretation and analyses are considered valid. We note the requirement to develop a qualitative and quantitative understanding of the present and future conditions; we found the absence of clear timeframe information made the presentation of the hydrogeological understanding, which used time-series data, difficult to follow. For example, it is not clear to what time period the conceptual model development process described in Section 3.3 of Volume 4 applies. Is it present day, the 2002 PCSC data freeze, or future site closure? Figures such as Figure 3.4 which purport to show trends in groundwater level are referenced to the 2002 PCSC (which implies that monitoring data collected since the 2002 PCSC data freeze has not been included), but no clarification or explanation of this is given in Volume 4. It is apparent from Henderson *et al*. (2008) that the calibration targets and boundary conditions are average values from 1995-1999, but even this choice is not adequately explained. Another clear omission in this regard is a discussion of other temporal variations and their potential significance to the hydrogeological interpretation (e.g. seasonal variations).

2.3.6 In places the validity of judgements and assumptions made in Volume 4 appears to be unsupported by the data and information supplied. For example, in Section 3.2.3 of Volume 4 it is stated that the source of the tritium contamination observed in regional and upper groundwater *"is considered to be the Trenches, as discussed in Volume 3….[which] indicates that the disposal of Beta Lights between December 1983 and April 1984 to Trench 6 accounts for the majority of tritium in the trenches."* On examination of Volume 3 there is a single short statement referring to tritium disposals: *"Over 80% of the LLWR tritium inventory is found within the trenches. Of this, the disposal of Betalights between December 1983 and April 1984 to Trench 6 accounts for the majority of tritium in the trenches."* An assumption therefore seems to have been made that a relatively discrete disposal of 80% of the total tritium is responsible for the current observed patterns of tritium contamination. The justification for this assumption is not immediately apparent – self-powered lighting such as the Betalights is most likely to have comprised a sealed tube or container enclosing gaseous tritium. The mechanisms driving the release of gaseous tritium into groundwater would therefore need to be identified and quantified. However, elsewhere in Volume 4 it is stated that tritium is only "believed" to originate from the trenches.

2.3.7 Regarding the general coverage of tritium within Volume 4 and supporting documents, it is disappointing that only limited work has been undertaken to improve the understanding of the release and migration of tritium from the site, which is clearly significant to understanding the past, present and near-term future conditions at the site. In contrast, LLW Repository Ltd have reported in Volume 3 substantial analyses to advance the understanding of the uranium, which is likely to have been driven by the contribution of uranium to the long-term impacts reported in the 2002 PCSC. The tritium data are important in understanding the previous and present groundwater flow paths and migration of radionuclides. We would therefore have expected further emphasis to be placed on developing and presenting a clear understanding of the tritium data within Volume 4. We recognise that some limited studies are presented in Henderson *et al*. (2008), but the poor knowledge of the source term (location, magnitude, release profile), combined with limitations due to the use of a model calibrated for the period 1995-1999 to assess conditions from 1955 to the present day, give us little confidence in the analyses. Further comments on the tritium transport model of Henderson *et al*. (2008) are included in Appendix 1 of this report.

2.3.8 Section 3.4 of Volume 4 presents the Source-Pathway-Receptor analysis which summarises the migration pathways of radionuclides *"between the source (the wastes in the near-field) and receptors (biosphere), which may be either direct or via the geosphere".* The purpose of this analysis as an aid to developing site understanding is not stated explicitly, but it seems to have been used to inform the development of the conceptual model (rather than being a conclusion of the conceptual model development). This analysis appears to be one example of where data collected since the 2002 PCSC has been used to update the analysis and, although the source of the additional data is not referenced, it seems likely that it is Ruddick and Foster (2007). On the other hand, there are also areas of the Source-Pathway-Receptor analysis which use event stratigraphy terminology from the 2002 PCSC. We note that this analysis was not described in any of the supporting documentation we have reviewed. We therefore assume that Table 3.2 was taken directly from the 2002 PCSC and updated in the production of Volume 4, but it is not clear why updating such an important area was not considered a legitimate part of conceptual model development and so reported in Sears (2007). Hence it is not clear to us whether the Source-Pathway-Receptor analysis and conceptual model are consistent with each other.

2.3.9 The description of the Source-Pathway-Receptor analysis would benefit from a clearer structure. For example, there is no *a priori* definition of the sources and receptors. The Source-Pathway-Receptor analysis is also another case in which the timeframes under consideration are ambiguous and create confusion. The summary analysis in Table 3.2 of Volume 4 does not offer the logical and comprehensive examination of the potential linkages between sources and receptors that would be expected during the development of a conceptual model. It is also not apparent that the analysis summarised in Table 3.2 is demonstrably comprehensive and robust to external events (such as site evolution and degradation of engineering features). Sources are not explicitly included in Table 3.2 but instead are inferred in the analysis of pathways and the receptors, which include a myriad of drainage features (e.g. Vault 8 drain, railway drain, OF1) and in some instances are a combination of pathway and receptor (e.g. East-West stream via railway drain). Furthermore, we found no mention in Table 3.2 of potential sources from future disposal areas or the effects of future engineering measures (e.g. potential vertical drain).

2.3.10 Table 3.2 of Volume 4 does not explain what weight was placed on the individual pieces of evidence to determine the overall classifications of pathways. For example, the migration of contamination to the intertidal zone via upper groundwater is described as “Uncertain” despite LP2 (which supports the upper groundwater unit) outcropping at the beach and measurable concentrations of tritium being detected in the intertidal zone. Historical detection of tritium in cliff seepages is given a “lower quality assurance” status than recent data which support an ephemeral pathway. In this instance it is not clear whether “Uncertain” is supposed to equate to ephemeral or why this pathway was classified as having a lower likelihood than some other pathways with apparently similar levels of evidence supporting at least an ephemeral pathway (e.g. upper groundwater northwest of trenches to gullies/ditches northwest of site).

2.3.11 In places the classifications in Table 3.2 could have been supported further by explicit reference to information available elsewhere. For example, where a pathway is uncertain (e.g. the migration of contamination to the East-West stream, below Frog gauging station, via upper groundwater), there is no explanation about how this is considered in the hydrogeological conceptual model and subsequent modelling studies, given the absence of a comprehensive treatment of uncertainty? An answer may be inferred by studying Volume 5, but this is not apparent from Table 3.2. Similarly, many aspects of the definition of the well are only explained in Volume 5, and their relevance and provenance are not at all apparent to a reader of Volume 4.

2.3.12 We expect LLW Repository Ltd, as they develop their hydrogeological conceptual model, to include a comprehensive and robust analysis of all potential linkages between sources and receptors throughout the assessment timeframe.

Model development

2.3.13 The hydrogeological data presented in Table 3.1 and described in the accompanying text in Section 3.2 of Volume 4 appear to be based largely on the existing datasets derived from the characterisation and interpretation work presented in the 2002 PCSC. Indeed some of the descriptions in Table 3.1 refer to measurements on lithologies in the now superseded event stratigraphy. If the primary data sources are unaltered, we would expect the mapping parameters between conceptualisations to be discussed. Furthermore, some parameters such as 'effective porosity' have been derived from previous modelling exercises conducted to support the 2002 PCSC; given the improvements to the conceptual modelling, it is not clear whether these parameters are still valid. Generally, the presentation of these data is unclear compared with data presentation elsewhere (e.g. Sears, 2007; Henderson *et al*., 2008). For example, it is not clear whether the data are intended as a demonstration of what data LLW Repository Ltd have collected, whether the reader is intended to bear these data in mind in the subsequent presentation of the development of the hydrogeological conceptual model or whether they actually represent the results of the conceptual model development.

2.3.14 One of the key points recommended by Bond (2006) for urgent attention is a review of key hydrogeological data, such as piezometric head data, to address issues of quality assurance that were highlighted in relation to values recorded in the database. We have also observed the need for an improvement in quality control of basic information sources in relation to the geological interpretation (see Section 2.2.9 of this review). We would be concerned if potential advances in geoscientific understanding and safety assessment calculations were based on sub-standard data or information sources and were therefore potentially flawed. LLW Repository Ltd should therefore consider taking the necessary steps to ensure that data and information are collected and stored to the highest quality standards. We will pursue this question with LLW Repository Ltd in the context of dialogue on their response to Schedule 9 Requirement 8.

2.3.15 Four potential explanations are quoted (from Sears (2007)) for the existence of vertical groundwater fluxes within the upper groundwater:

(a) Lithological discontinuities between geological features.
(b) Lithological heterogeneities within geological features.
(c) Structural features (faults and fissures).
(d) Low permeability material.

Sears (2007) states generally that *"vertical head differences principally result from the effect of the less permeable clays and silts that result in vertical flow rates that are lower than local recharge rates".* However, no attempt has been made to use the results of the reinterpretation of the geology to enhance the hydrogeological understanding (e.g. via the use of thick slice cross-sections); this does not give us confidence in either the process undertaken or the robustness of the underlying conceptual model. It is not clear how the parameterisation of the calibrated model of Henderson *et al.* (2008) relates to these potential mechanisms and this is a clear gap in the hydrogeological understanding.

2.3.16 Section 3 of Volume 4 provides no clear summary or pictorial representation of the proposed conceptual model described in Sections 3.3 and 3.4, unless Figure 3.1 is an attempt to provide such a conceptual understanding. The absence of a diagram means it is difficult to bring to mind the basis for the hydrogeological conceptualisation when discussion re-starts in Section 5 (describing the hydrogeological conceptualisation on which the modelling studies are based). A graphical representation of the conceptual model such as Figures 8 and 9 of Sears (2007) might reduce this difficulty. However, we note that these pictures are referenced to the 2002 PCSC and therefore might need updating.

2.3.17 Three modelling exercises are summarised in Section 5: a regional-scale model; a saline interface model; and a site-scale model. Given the importance of underpinning a site-scale model within the appropriate regional context, we have some concerns that the development of the regional and saline interface models have been discontinued. It seems that the saline interface model is considered no more than a "useful starting point" and the regional model does not seem to reproduce a good fit to the observed data. The limitations in these studies do not seem to have always been considered (for example, the saline model has been used to support the development of conceptual and numerical models elsewhere). We note that the first two models were implemented by one set of contractors to LLW Repository Ltd whereas the last was produced by others. Occasional changes of contractor may be a fact of life for site operators, but we cannot make allowance for such changes in our evaluation of an ESC and we expect to see evidence of coherent programmes of work pursuing consistent objectives. Further comments are provided on the saline model studies of Bond (2007) in Appendix 1 of this report.

2.3.18 The "site-scale flow and transport" model is stated to be *a "steady-state, saturated media, for an unconfined aquifer with an upper phreatic surface"*. No justification is given for assuming that these limitations are appropriate and that all important features and processes of the hydrogeological conceptual model are still represented. For example, it is apparent that an early version of the site-scale model did not incorporate the engineering features presently in existence at the site (e.g. cut-off wall between the trenches and the railway cutting); this early model was designed to serve as a quasi-regional model. The site-scale model is stated to be applicable to "current conditions", but doesn't specify whether this means the present day, the timing of the 2002 PCSC data freeze, or another date (as noted previously, the supporting documentation indicates 1995-1999). Given the proposed application of hydrogeological modelling to future scenarios, it would be particularly relevant to describe the approach taken to represent evolution, for example by using a transient simulation or a series of steady state "snapshot" simulations.

2.3.19 The site-scale hydrogeological model comprises eight lithofacies packages and the underlying sandstone. Lithofacies packages LP2 & LP3 are undivided in the site-scale hydrogeological model and two regional lithofacies packages LB3 and LB4 are included. The description of the modelling studies refers to the version 1 model, but this is confusing because this version of the model failed to calibrate satisfactorily and therefore does not contribute to advancing geoscientific understanding (see comments below).

2.3.20 The description of the modelling studies focuses on the site-scale model exercises and describes "base case" and "version 2 base case" models. The limited description of the structures of these models, their purpose, similarities and differences makes the presentation confusing. Furthermore, it would also be appropriate for a document on site understanding to present a summary of the regional and saline interface model and an overview of the breadth of modelling work undertaken and the extent of any inter-connections.

2.3.21 The annual recharge value applied to the areas of the site-scale model representing the trenches (174 mm) is high compared to the surrounding areas and to estimates for the closure engineering of 10 mm. Clearly one of the primary purposes of installing a cap over the trenches is to reduce the amount of infiltration received by the wastes and this parameterisation therefore raises questions about the performance of the cap. Are LLW Repository Ltd confident that the value of 10 mm/y is achievable for the final cap, given that 'experience' of operations at the site (presumably with the interim cap) is an infiltration rate of 174 mm/y?

2.3.22 In our view, the description of the "base case model" (c.f. version 1 site-scale model; Arthur *et al*., 2008b) detracts from, rather than adds anything useful to the discussion in Volume 4. It is clear from Arthur *et al.* (2008b) that the model failed to produce an acceptable calibration and therefore was not successful in demonstrating a quantitative understanding of the hydrogeological processes on a site-scale. We are not clear as to why this work has been referenced in Volume 4.

2.3.23 Neither the purpose nor the scope of the "version 2 base case model" relative to the "base case model" is clear from Volume 4. The representation of engineering features within the model is not described, and it is therefore not readily apparent what advances the version 2 model represents over the "base case model" or indeed why development of the "base case model" ceased at the point it did. This information can be obtained by reviewing Arthur *et al.* (2008b) and Henderson *et al*. (2008), but a clear description of the sequence of modelling activities within Volume 4 would have been helpful (assuming that reference to the version 1 model is actually necessary). Overall, we have the impression that the hydrogeological modelling work was still being carried out during the production of Volume

4 and that this has led to the rather confused reporting in Section 5 and a reduction in the quality of key aspects of this Volume.

2.3.24 Henderson *et al*. (2008) report that during calibration of the base case model, the decision was taken to vary the horizontal and vertical hydraulic conductivities of LP2/3 such that the ‘standard’ assumption of 10:1 anisotropy ratio was not honoured. On page 17 of Henderson *et al*. (2008) it is stated with regards to hydraulic conductivity that *“there is little difference between the different lithofacies packages”*, so we would therefore expect further justification to support the decision to retain a 10:1 anisotropy ratio for other lithofacies packages. Is it possible to achieve the required vertical gradients by reducing the vertical conductivity of other lithofacies packages, such as LP4? One of the advantages of using an automated calibration procedure such as PEST is that a relatively large range of parameter values can be considered within a calibration exercise. However, reasons are not given for restricting the calibration process so that the anisotropy ratio was only varied in LP2/3. It is not clear whether this parameterisation is believed to represent all four possible explanations made in Sears (2007) regarding the existence of vertical gradients (see para. 2.3.15 above) or only one of them. If the latter, how will the other possibilities be assessed? Other potentially important geological information appears to have been ignored. For example, potential channel features were identified from the thick slice cross-sections; these features might suggest that hydraulic conductivity may not be the same in the x- and y-directions, as was assumed. Such additional information would build confidence in the level of agreement reached.

2.3.25 The results of particle tracking simulations using the calibrated “version 2 base case model” are used to illustrate the directions of groundwater flow. The flow within the Quaternary sediments is modelled with a simplified approach and there is no uncertainty analysis; some degree of caution should be exercised therefore when interpreting the forward and reverse particle tracking. It would be relevant for the interpretation to discuss whether hydrodynamic processes such as dispersion were included in the modelling and, if not, justify using results obtained under these circumstances.

2.3.26 In interpreting the tritium transport model, Henderson *et al*. (2008) suggest that the dispersive plumes produced by the model are limitations in the numerical scheme. They do not consider that the source term may be too poorly defined to make the results credible. Similarly, when attempting to compare predictions of the tritium distribution through time, little consideration seems to have been given to the potential timing of disposals, the previous developments at the site (e.g. trench construction, interim cap emplacement) and the fact that the steady-state model was calibrated using boundary conditions and targets from 1995-1999. As noted previously, in Section 3.2.3 of Volume 4 it is stated that the source of the tritium contamination observed in the regional and upper groundwater *“is considered to be the Trenches, as discussed in Volume 3….[which] indicates that the disposal of Beta Lights between December 1983 and April 1984 to Trench 6 accounts for the majority of tritium in the trenches.”* Therefore it is not apparent why a uniform distribution throughout the trenches was assumed, nor why simulations were started at 1955.

2.3.27 As noted previously, LLW Repository Ltd do not clearly describe the conceptual model of tritium release. Henderson *et al*. (2008) assume that this omission is acceptable during the early stages of the tritium model’s development, but this assumption ignores the fact that LLW Repository Ltd should be able to demonstrate an understanding of the mechanisms underlying tritium release and migration as part of their operational management of the site. As stated previously, this understanding should also be used to inform the development of the conceptual model for groundwater flow. Results from the tritium transport model are not presented in Volume 4, which is in our view an odd omission, given that the tritium data represent the most obvious potential source of direct evidence about the behaviour of groundwater at the site.

2.3.28 A limited number of additional model simulations have been undertaken to assess the potential hydrogeological conditions when environmental conditions and engineering features are changed. Three ‘situations’ are identified which focus on changes in climate and landscape. However, we are surprised that the most important 'situation' (i.e. the reduction in the distance to the coast) is not considered *"as it has been assessed directly within the risk assessment."* We note that the effects of changes (increases) in sea-level combined with costal erosion are likely to alter both the position of the upper and regional groundwater units and the relative magnitude of groundwater fluxes. Furthermore, coastal erosion may change the nature of (e.g. widen) the inter-tidal zone. The magnitude of such changes is expected to increase over time as the rise in sea-level and coastal erosion progress, so the analysis is sensitive to time. It is not immediately apparent that the effects of such changes could or will be addressed within the "risk assessment".

2.3.29 The rationale behind the identification and description of Scenarios 1 to 5 – and how they link to the EPA (Paksy, 2008) and with general views on future performance – is not clearly presented. The source of the scenarios should have been presented and their links with the EPA and elicitation workshops should have been documented clearly.

2.3.30 The simulations to represent future performance scenarios are not described in any detail. It is our view that the results of these simulations would merit more attention than the current single page in Volume 4. The majority of the text describes the results from Scenario 1 (fully effective engineering), but the clarity of the analysis is reduced by the lack of information relating to the time frame it represents, the absence of a cross-section and lack of detailed comparisons with the results from the "version 2 base case" model.

2.3.31 A more detailed presentation is given in Henderson *et al.* (2008), but it is not clear whether any checks were undertaken on the model results for Scenarios 1 to 5 to confirm that the model configuration was producing an acceptable solution. We think such checks are particularly important because:

(a) the original calibration was across a relatively narrow time range,
(b) there is no accompanying sensitivity study for the simulations,
(c) the mesh properties and boundary conditions (used to represent the closure engineering and changed boundary conditions) were altered.

The interpretation of results relies heavily on simulations of particle tracking, but they are not supported by a thorough examination of their limitations and uncertainties. Given the limited scope of the simulations undertaken, such caveats should have been identified and discussed.

2.3.32 We are disappointed by the limited discussion in Volume 4 about the links between the outputs of the site understanding and the requirements of the performance update. The text does not provide a clear description of how the analyses reported within Volume 4 are used to configure and supply parameters for the performance update calculations. For example, the limitations in the scope of the hydrogeological modelling (e.g. steady-state, lack of stated timeframes) and associated assumptions (e.g. that particle tracks provide an appropriate proxy for contaminant transport) should have been discussed. The impact of these issues should have been considered in the development of a robust set of calculations for the performance update (especially given the lack of uncertainty analyses).

2.3.33 Overall, the description of the parameterisation of the performance update model presented in Volume 4 lacks the logic and rigour that we would expect in a full ESC.

2.3.34 Some further description of the interface between the hydrogeological modelling and the performance update calculations is provided in Henderson *et al*. (2008). It is noted that GoldSim uses 10 pipes to represent groundwater flow, compared to the 1.8 million elements of the FEFLOW model[6]. Numerical dispersion within the GoldSim model is not discussed, and no comparisons of estimated fluxes from the two models are provided, so it is difficult to be confident that the GoldSim representation was adequate.

[6] Obviously significantly fewer than 1,800,000 FEFLOW elements will represent the pathways from the disposal areas but there will be significantly more than the 10 used in GoldSim.

2.3.35 The exclusion of horizontal transverse dispersion and the inclusion of vertical transverse dispersion represent a mixture of cautious and non-cautious assumptions. Such a mixture of assumptions may not be helpful when assessing whether the final calculations are cautious or not. No information was provided on the treatment of longitudinal dispersion within GoldSim. More generally, and linking to previous discussions on numerical dispersion, we find no information on the Peclet number assumed in the GoldSim calculations, nor how this relates to the estimates of dispersivity used within FEFLOW and derived from site-specific data.

2.3.36 From the configuration presented in Volume 4, it is unclear how pathways through a degraded cut-off wall may be represented within the model (including the potential for discharge to surface water). It seems that (rather optimistically) the model assumes that radionuclides can only leave the near field vertically downwards. It is not clear why it was considered inappropriate to extend the GoldSim model used in the EPA (Paksy, 2008) to the geosphere-biosphere interface, as this would have increased the level of consistency with the EPA.

Treatment of uncertainty

2.3.37 As noted previously (and acknowledged by LLW Repository Ltd), the level of analysis of the effects of uncertainty in Volume 4 would not be sufficient for a full ESC.

2.3.38 In addition to areas of hydrogeological uncertainty that may result from adopting the lithofacies-based approach to the interpretation of the geology, we note several uncertainties in the hydrogeological interpretation in Volume 4. In some places the uncertainties relate to relatively fundamental issues, for example the basic intent in the orientation and dip of the trenches, or the depths of the railway cutting and associated drain. Given that these basic uncertainties were also common to the 2002 PCSC, it is not apparent why steps have not been taken to resolve such issues in the interim.

2.3.39 A key area of focus for the work presented in Volume 4 is stated to relate to *"the issue of what supports the vertical hydraulic gradients".* Four possible explanations are presented, namely:

- lithological discontinuities;
- lithological heterogeneities;
- structural features;
- low permeability material.

However, these explanations have not been ranked or prioritised in terms of their importance to the conceptual model. No information is provided about which of these explanations are considered within the conceptual model presented or what the potential effects of adopting an alternative approach would be.

2.3.40 The treatment of uncertainty in Volume 4 and the supporting documents would not be adequate for a full ESC; we expect LLW Repository Ltd to address this omission in their work towards meeting Requirement 6. To demonstrate an adequate treatment of uncertainty, it is necessary that sources should be identified, described, prioritised and their effects on the safety assessment should be determined so that a plan can be established (and executed) to reduce any areas of uncertainty that have significant impact on the safety assessment.

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2 Conclusions in relation to Schedule 9 Requirement 2

3.0.1 As discussed previously, Requirement 2 requires the operator, by 1 May 2008, to *"provide the Agency with a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events (e.g. coastal erosion and glaciation) and potential future human action."*

3.0.2 Volume 4 is a supporting document which relates to Requirement 2, but it does not provide a direct response to the Requirement. No conclusions can be made therefore in this review in relation to the adequacy of Volume 4 in meeting Requirement 2.

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3 Recommendations in relation to the environmental safety case

4.0.1 Requirement 6 requires the operator, by 1 May 2011, to *"update the Environmental Safety Case(s) for the site covering the period up to withdrawal of control and thereafter"*. The purpose of this update is to address our criticisms of the 2002 environmental safety cases and supporting programmes (Environment Agency, 2005a, 2005b, 2006), and to take account of developments since the 2002 environmental safety cases were finalised. Such developments would include evolution of operating practices, additional information on the site, the design of the repository and the waste inventory, changes in ownership, and developments in Government policy (Defra *et al*., 2007) and regulatory guidance (Environment Agency *et al*., 2008).

4.0.2 As noted previously, the Environment Agency's requirements regarding an environmental safety case are presented in the GRA. The GRA requirements particularly relevant to the content of Volume 4 have been previously presented in Section 2.

4.0.3 We note that the submissions made by LLW Repository Ltd on site understanding, in relation to Requirement 2, are more limited in scope than we would expect for an environmental safety case. This is acceptable because Requirement 2 does not specifically require site understanding to be addressed, although various aspects of Requirement 2 are supported by understanding of the site. We expect LLW Repository Ltd to develop a more substantial summary of site understanding to support the environmental safety case(s) due for submission by 1 May 2011 under Requirement 6. This review has highlighted several areas which require further attention during the preparation and presentation of the Requirement 6 submissions.

4.0.4 It is important that LLW Repository Ltd (**Category A recommendation** – see para. 1.5.4 above) provide a clear description of their overall approach to develop their understanding of the site. The approach should integrate information from site characterisation, modelling studies, facility design, construction and operation. For a full ESC, the breadth of activities and disciplines that will need to be employed is wider than those that were needed to respond to Requirement 2. For example, the site understanding for the full ESC will need to include adequate consideration of elements of geoscience not addressed explicitly in any detail in the Requirement 2 submission (e.g. geochemistry), and of the interface between conditions in the operational and post-closure phases. We emphasise that LLW Repository Ltd's approach to developing an understanding of the site should enable iteration of individual activities (e.g. refining the hydrogeological conceptual model) and the overall cycle (i.e. conceptual models of geology and hydrogeology, hydrogeological modelling, assessment). Their approach should link clearly to a forward programme.

4.0.5 We recommend that LLW Repository Ltd (**Category A recommendation**) commit further effort to developing a clear understanding of the mechanisms controlling the release and migration of tritium within the groundwater. At present this source term is poorly understood (in terms of location, magnitude, release history and form), so attempts to compare observations with model output are of questionable value. We note that, even if LLW Repository Ltd determine that the post-closure safety of the site is not heavily dependent on the groundwater pathway, they still must consider the potential impacts during the remainder of the operational phase of the site.

4.0.6 LLW Repository Ltd should (**Category A recommendation**) establish and report the hierarchy of models used to develop and support site understanding and to meet the wider requirements of the LLWR safety assessment programme. For example, LLW Repository Ltd have not adequately justified why they developed a site-scale model in isolation from other supporting models of a suitable maturity (e.g. regional, saline interface), nor have they adequately explained their reasons for adopting a steady-state model (as opposed to a transient model). LLW Repository Ltd should also consider the wider requirements of the safety case. For example, the links between the engineering performance assessment and safety assessment calculations should be carefully designed to ensure that interfaces between models are well defined and maintain consistency, and to build confidence in the ESC.

4.0.7 It is not required or necessary for the Requirement 2 submission to address uncertainty in full, however we note that the treatment of uncertainty within Volume 4 and the supporting documents would not be adequate for a full ESC. LLW Repository Ltd should (**Category A recommendation**) identify, describe and prioritise sources of uncertainty, assess their effects on the safety assessment, and establish and implement a coherent programme of actions to reduce any areas of uncertainty that have a significant impact on the safety assessment.

4.0.8 Our review has also identified several issues that are not critical to the response to Requirement 2, but we consider will need to be addressed for the Requirement 6 submissions. These issues are listed below:

(a) The technical presentation of site understanding should be reviewed (**Category B recommendation**) to provide a clear and balanced description of all aspects relevant to the ESC. To do this, LLW Repository Ltd will have to establish strong project management, to establish and enforce data freezes and to deliver high quality safety case documentation. LLW Repository Ltd should (**Category D recommendation**) decide on the document hierarchy that best demonstrates site understanding in a clear and auditable manner. A document structure containing several sequential 'update' documents does not enable clear presentation (or audit).
(b) LLW Repository Ltd should (**Category D recommendation**) provide a clearer justification for their decision to use a lithofacies approach to the geological re-interpretation. They should ensure that the work to extend site understanding for the full ESC includes sufficient iterations between the geological and hydrogeological disciplines in the key areas of interest.

Additionally, we recommend that LLW Repository Ltd:

(a) assess the quality of the underlying data used to support the geological and hydrogeological analyses in the light of a number of errors that have been identified in our review of the Requirement 2 submission (Environment Agency, 2009c) (**Category C recommendation**);
(b) ensure that the geological and hydrogeological analysis is based on all the available data, including results from on-going monitoring at the LLWR (**Category C recommendation**);
(c) substantiate their approach to geological modelling and the reasons for selecting different software tools for regional and site scales (**Category D recommendation**);
(d) review the source-pathway-receptor analysis (if it will continue to be used) to ensure that it provides a clear presentation of the analysis of potential routes by which radionuclides may migrate from the disposal facility to various receptors over the timescales of the ESC (**Category D recommendation**);
(e) identify and assess whether additional measurements in the field are needed to support site understanding (e.g. to provide data on the height of the railway cutting and associated drainage features) (**Category C recommendation**);
(f) ensure that the general quality, presentation and consistency of the documentation that covers the site understanding work in the full ESC promotes understanding and facilitates its review (**Category D recommendation**).

4.0.9 Appendix 1 of this report lists a substantial number of relatively minor observations from our review of several key supporting documents to Volume 4 (any more substantial issues from these documents having been reflected in the main text of this report). We recommend (**Category D recommendation**) that LLW Repository Ltd take note of these comments, and act upon them as appropriate, in preparing the full ESC.

Appendix 1 – Review of supporting references

This appendix provides detailed comments on a number of the documents cited to support Volume 4 of the Requirement 2 submission. The main points arising from our review of these documents are, however, addressed in the main text.

Smith, N. 2006. LLWR Lifetime Project: LLWR Geological Reappraisal – Review of 2002 PCSC Geological Interpretation (BNFL, 2002) and agreed recommendations.

This supporting document is a Nexia Solutions memorandum purported to be the record of a workshop held on 29 November 2006 to discuss the potential approaches that could be followed to review the geological interpretation.

As the document is a memorandum it has not been subject to the same level of quality assurance as a report or technical note. The document contains no reference number, unlike the corresponding citation to it in Hunter *et al*. (2007), so it is uncertain whether the document provided to the Environment Agency by LLW Repository Ltd is the same as the one cited by Hunter *et al*. (2007).

Given that the geological reinterpretation depends so significantly on the selection of an appropriate reviewing technique, the reporting of the decision-making process is judged to be inadequate for the following reasons:

(a) The details of the workshop are not stated within the record.
(b) The purpose and scope of the workshop are not made clear. It is not clear whether an approach had been derived prior to the workshop and had then been presented to attendees for approval, or whether the approach selected was a result of discussions within the workshop.
(c) It is not clear that the comments and recommendations from both BNFL's independent peer review and the Environment Agency's regulatory review of the 2002 PCSC had been sufficiently addressed. The memorandum contains some appended comments on the 2002 PCSC Geological Interpretation (BNFL, 2002), which may have resulted from discussions at the workshop, or may have been derived by the author himself. However, these are largely focused on criticisms of the presentation of the 2002 PCSC Geological Interpretation and are therefore not a surrogate for the review findings and recommendations themselves.
(d) If several potential techniques were presented for discussion at the workshop it is not clear what they were, what criteria were used to assess them and why the lithofacies-based approach was selected over the other techniques.
(e) The personnel present are not stated. The memorandum is addressed to the LLWR Geological Reappraisal Team, and therefore the balance of skills and experience brought to the workshop cannot be judged.

Hunter, J., Michie, U.McCl., Smith, N.T. and Towler, G., 2007. LLWR Lifetime Project: Reinterpretation of the Quaternary geology of the LLWR Site and the surrounding region. Nexia Solutions Report No. (07) 8345. Issue 3. August 2007.

General

The report provides a comprehensive account of the process underlying the review of the geological interpretation and its conclusions.

The report seems generally well written (assuming it was intended for a geological audience), but we find evidence in some places of sub-standard quality control (e.g. illegible figures in the electronic version, absence of a glossary, 'Track Changes' comments left in, missing map legends, incorrect pagination) which detracts from the product. The report could be improved significantly by some restructuring and modifications to make it more robust and build confidence in it. Generally the reinterpretation process seems to have been carefully and soundly reasoned and to have given proper consideration to the data available and to previous interpretations. The new approaches applied in this study – notably the 'thick slice' analysis of borehole data – appear to provide significant additional insight, even if the results are rarely conclusive.

Nevertheless, the result is a conceptual model that, by the authors' own admission, includes elements of speculation about what is clearly a complex system. We find this speculation to be generally internally consistent, based on sound scientific principles, and more consistent with the available evidence than the alternatives. However, the sparseness and variability of data still leave considerable room for uncertainty. We are concerned that this uncertainty should not be forgotten even if the geological reinterpretation used from this point on is treated as *the* model. Naturally, the interpretation thought to be the most plausible should have a central role in informing the hydrogeological interpretation and modelling, and the wider environmental safety case. However, to treat the geological conceptual model as a certain basis for further work would misrepresent the actual level of uncertainty present. We would expect to see an appraisal of the possible implications resulting from other plausible interpretations of the geological evidence that exists. Whether this is best addressed using bounding arguments, an assessment of alternative 'scenarios' or via probabilistic methods is a matter for LLW Repository Ltd.

Background and data sources

Section 2.3, Figure 2 of the report should contain all the important features of the bedrock geology discussed in the text, such as the Lake District Boundary Fault Zone. As noted previously, a summary of the solid geological succession that shows a consistent level of detail with those derived for the lithofacies would be a valuable inclusion.

In Section 2.4, the report makes no reference to the ongoing work of the BGS to update the Quaternary lithostratigraphy (e.g. McMillan *et al*., 2005). The chronostratigraphy in McMillan *et al*. (2005) appears slightly different to that summarised in Section 2.4. This seems particularly odd given that one of the BGS authors of the cited report took part in the fieldwork described in the report. The legend to Figure 3 does not contain all the Quaternary sediments shown in the cross-section.

Given the comments in Section 3.3 of the report on the potential for errors within the DSCP borehole database, it would have been opportune to undertake a programme of quality assurance when abstracting data for use in the review of the geological interpretation. This would provide some information on the potential scale of these errors and allow their impact to be better assessed.

Lithofacies approach

It would be relevant for this supporting document to indicate who participated in the workshop held on 29 November 2006 which is mentioned in Section 4.1 of the report. At the very least it would be beneficial to know the level of any involvement of people from outside the project team – was this essentially a meeting between the authors or was a broader range of views obtained? We recognise that the use of an approach based on lithofacies over one based around 'event stratigraphy' may represent an advance, but it seems that several of the units defined in the PCSC (Main Diamict, Pebbly Clay Formation, Lacustrine Fluvial Formation etc.) are readily mappable onto the lithofacies units identified here. Furthermore, how does the lithofacies approach improve on the identification, discretisation and characterisation of key strata or lithological horizons (from a set of heterogeneous deposits) which may ultimately control radionuclide migration? What other approaches were considered and what criteria were used to select the lithofacies approach over others?

In Section 4.2 of the report it would have been helpful to discuss the reason(s) for reinterpreting the site and regional scales at the same time. The advantages seem to be related to overall project programming, but what are the disadvantages of this parallel approach compared with a reinterpretation of the whole region first, then a subsequent refinement at a site scale? Would such a suggested approach have prevented the difficulties encountered in correlating some of site scale information to site scale lithofacies packages? A parallel approach to local and regional spatial analysis is not best practice for hydrogeological studies, so why is it acceptable for the geology?

How was the approach to the reinterpretation detailed in Section 4.2 derived? Has it been reviewed by other geologists with experience in Quaternary geological successions? Were any limitations found in using the data (e.g. lithologies recorded in the DSCP borehole database) to derive the lithofacies packages and how were such uncertainties overcome?

In Section 6.3 of the report, it would have been relevant to describe the “distinct characteristics” that were considered pertinent to the simplification of the BGS lithostratigraphy. It would be helpful to explain why these characteristics were considered to be hydrogeologically pertinent and how they differed from the hydrogeological domains concept developed by Nirex and previously criticised in this report as not suitable for the LLWR. It is later stated in the same section that unit B3 was subsequently divided into two distinct units with the same hydrogeological properties. Why was this subdivision considered necessary (Figure 3 offers little support), how is it consistent with the overall approach to derivation of lithofacies units and what other concepts could have been adopted to describe the distribution of sediments?

How is it possible to state *a priori* that the number of hydrogeological units identified within a geological interpretation is sufficient for a regional hydrogeological model? The suitable number of units is judged according to the perceived requirements for groundwater flow, but the ultimate end use of the interpretation is to provide estimates of contaminant transport. How might these requirements differ from those of groundwater flow? Given the heterogeneity in the Quaternary sediments, what degree of certainty is there that the data used to derive the regional geological interpretation (which may contain relatively large amounts of information from non-intrusive investigation techniques) does indeed contain sufficient information to characterise the spatial variability in hydrogeological properties.

We would expect a fuller version of the discussion contained within Section 6.2 and 6.3 to be reported to justify the selection of a lithofacies-based approach over other approaches to geological interpretation and the development of a geoscience model.

Regional geological model

In Section 6.5.1 of the report a fuller description of the assumptions involved in the geological modelling would have put this stage of the work into context; it would also reduce the need to read Smith (2007a). The modelling results seem to have been used at face value to redefine the lithofacies (e.g. subdivide B3, diachronous nature of B4) and there is no indication whether the primary data sources were re-visited to assess whether the findings are supported by means other than modelling. Were outputs from the regional geological model compared with existing regional transects? Why was it not possible to construct thick slice cross-sections for areas of high data density outside of the LLWR (e.g. Sellafield)?

It is also noted that the regional and site-scale modelling exercises used different software, but there is no discussion on the potential implications of this for the overall geological interpretation. Have these sources of uncertainty been recognised and investigated?

Site scale geological interpretation

The use of thick slice cross-sections to interpret the site-scale geology appears to provide additional insights. However, the technique needs to be described in more detail to fully support its use within the geological interpretation. For example:

(a) no basis is given for selecting a 200 m width for the cross sections and there is no indication of whether alternative widths were considered and whether this may result in different conclusions being drawn;
(b) it is unclear whether the use of thick slice cross-sections supported by field mapping represent the preference of one author for manual interpretation over the geological modelling techniques;

(c) comparisons of the thick slice cross-sections and site-scale modelling are not presented, but such comparisons would be welcome as part of a confidence building exercise;
(d) given the width of 200 m for thick slice cross-sections, it is not clear what correlation length this may imply, nor how it compares to the correlation lengths associated with the use of geological modelling techniques?

In the version of Hunter *et al*. (2007) provided to the Environment Agency, an error exists in the pagination of Appendix 2 after page 114, so many of the figures are not legible.

It is not clear whether, at the time of the field visits, the lithofacies framework had been identified and selected for use at either the regional or site scale. Were the site visits designed to confirm the suitability of the lithofacies developed or were they part of the development process for the lithofacies framework?

Reference is made to a photograph of Nethertown Cliff in Appendix 3 but this appendix is not present in the version of Hunter *et al.* (2007) provided to the Environment Agency.

Figure 56, which is stated to show a consistent result following integration of the regional and site scale models, requires further explanation as to how it supports the statements made. Additionally, when suggesting that the lower surface of the Holmrook Till (Package C and 4) are at "approximately similar elevations", further clarification of the differences between the two models and the reasons for those differences are required.

A simple summary of the site-scale lithofacies packages would have been a useful addition to what is a rather long description of the identification of the packages themselves.

Smith, N. 2007a. LLWR Lifetime Project: Reinterpretation of the Quaternary geology of the LLWR Site and the surrounding region: Regional and site-scale 3D Geological Modelling. Nexia Solutions Report (07)8509. Version 1.0. May 2007.

General

This report provides a description of the three-dimensional geological models developed at a regional and site scale for LLW Repository Ltd in support of Requirement 2. The report shows numerous screen captures from the software used to produce the three-dimensional models; the description and annotation of the figures is generally insufficient to support the claims made in the accompanying text.

Modelling approach

The site-scale modelling used 3DAnalyst (a module of ArcGIS) whereas the regional scale modelling used RockWorks. However, the exact reasons for the selection of different software for each scale is not entirely certain. In particular, the decision to model geological surfaces rather than blocks is not discussed at the outset, nor is any comparison made with approaches or results from geological modelling previously conducted by Nirex. It is suggested initially that there is insufficient site-scale data for the "complex modelling processes" performed by RockWorks, but it is later stated that RockWorks is better suited to processing large sets of data. Elsewhere (e.g. Hunter *et al*., 2007) it is suggested that differences in data densities were the main reason for interpreting the geological data at two different spatial scales. Elsewhere in the report, the decision not to use the 'triangular irregular networks' TINs approach to create three-dimensional surfaces seems to be related to the amount of data available for use. Within the approach chosen, again a high importance seems to have been placed on the ability of the model to produce "a single 3-D model". The two models were also combined as part of a "validation exercise" using a third piece of software, ArcScene (previously described as a visualisation package).

Further errors were noted in the LLWR lithology database (variable quality of logs, transcription errors for lithological data and co-ordinates, and uncertainties/errors in interpreting sediment types and assigning plotting codes). It is noted in Section 4.3 of the report that there are *"a number of* *quality-assurance issues associated with the LLWR lithology database"* which adds to our concern, given the statement made in Hunter *et al*. (2007) concerning an "unknown" number of errors.

The validation of the regional geological model against input data such as BGS regional transects is discussed, but the appraisal tends to give an over precise impression which is inappropriate given the subjective nature of some of the interpretation required to produce the transects, and the previously identified errors in other data sources. Furthermore, this "validation" process seems to have influenced the geological interpretation itself – the results have been used to propose the sub-division of some lithofacies packages.

Results

Generally the results are interpreted without reference to any associated uncertainty. For example, at the site scale the thick slice cross-sections produced by Hunter *et al*. (2007) are simplified (shown in Figure 8B of the report). This simplification is based on numerous assumptions and introduces additional uncertainties, the effects of which seem untested in the accompanying analysis. Aspects of the data extrapolation and interpolation routines are discussed in Section 5.4 ahead of the results. It is stated that the models "are accurate enough" to be used for the development of a hydrogeological conceptual model, but again there is no appraisal of alternative three-dimensional geological conceptualisations that would still be consistent with the data, given the methodological or data uncertainties. The exception to this observation is the discussion of the gravel-filled incision channels of lithofacies package 3, in which an alternative interpretation is suggested based on vertical exaggeration (i.e. on the basis of simply viewing the output in a different manner); it is noted that *"these two possible explanations may not be the only ones…"*. The sparse data are briefly covered in the conclusions which suggest that the lack of data may lead to overestimates of sediment thicknesses.

A more structured and thorough consideration of uncertainty is required throughout the geological modelling studies in order to build confidence in their output.

Smith, N., 2008. LLWR Lifetime Project: Phase II Geological Reinterpretation: Further 3D geological modelling of the Quaternary geology of the LLWR Site and the surrounding region. Nexia Solutions Report (07)8885. Issue 3. April 2008.

The main update in this *Phase II report* seems to be some redefinition of the boundaries between the lithofacies packages proposed earlier by Hunter *et al.* (2007). The main consequence of this change seems to be that the gravel-filled 'incised channels' proposed by Hunter *et al*. are believed to penetrate only partly into the main till layer rather than all the way through as suggested previously. However, there is no clear indication that this is a demonstrable improvement in the interpretation, as opposed to an alternative interpretation; there does not seem to be any more hard evidence to support this interpretation than the previous one. At best, this redefinition seems to represent a shift in the relative levels of 'belief' or confidence between two alternative interpretations, based on a combination of some previously unpublished data (additional BGS transects and old resistivity profiles) and some further reinterpretation. As the author of the Phase II report is one of the four authors of the earlier report, it is not clear to what extent (if any) the update reflects that author's particular interpretation.

The modelling work uses a single combined model rather than the separate models used previously for the regional and site scales. However, the software chosen is RockWorks which was initially flagged as inappropriate for use at the site scale during the Phase I studies. It is not clear what data or procedures have changed that now make this software applicable for use with site data.

On several occasions there appears to be a tendency to report the modelling results without much caution about the effects of assumptions on the results; any uncertainty in the results appears to be ignored. Although uncertainties are discussed on some occasions, it is not always clear that they are considered within the final "single geological concept" presented.

It would not be immediately obvious to somebody who has not been intimately involved in the reinterpretation why materials of apparently similar composition should be ‘moved’ from one lithofacies package to another. It is similarly difficult to understand when differences between areas that are relatively rich in sand and/or gravel are considered as spatial variability in the composition of the same package and when they would become separate packages on the basis of their different composition. Is this entirely a matter of judgement, and if so, why should we trust the judgement of the latest author more than that of previous ones?

Bond, A.E., 2007. LLWR Lifetime Project: v0 Saline Model. Nexia Solutions Report No. 8506.

Scope

The specific objectives of the initial saline modelling require further explanation to clarify the apparent contradictions in those stated. One stated objective of the modelling is *“to be consistent with the regional modelling”* whilst another is to “inform” the subsequent revision of regional models. Bond (2007) also notes that the purpose of the study is *“to test the usefulness and practicality…for LLWR’s needs”.*

Approach

It is noted that the modelling simulations are steady-state, an assumption considered by Bond (2007) to be “reasonable and practical” for the initial stage of the study and its focus on present-day conditions.

The two-dimensional section used to implement the saline model and its geometry was identified using the regional model of Towler and McGarry (2007); flow parameters from this study were also used despite the fact that output from the calibrated model did not agree well with observations and was deemed unacceptable by the authors themselves. Therefore the model parameters, if based on those reported by Towler and McGarry (2007), may not represent a suitable dataset on which to undertake further modelling exercises.

It is also noted that, during the parameterisation of the model, the Quaternary deposits were stated to be of lesser importance compared to the deeper geologies, they were hence simplified to a single layer in the model and their hydraulic conductivity was set at the upper end of the range considered by Towler and McGarry (2007). However, the potential effect of this simplification is not re-visited when the results of particle tracking simulations conducted in the Quaternary deposits are interpreted.

A relatively limited number of sensitivity studies were undertaken, but it is surprising that they did not include at least an initial appraisal of the potential uncertainty in the saline interface to uncertainties in hydraulic conductivities, particularly given the observed importance of contrast in values within the Calder Sandstone.

Sears, R., 2007. LLWR Lifetime Project: Hydrogeological Conceptual Model. Nexia Solutions Report No. (07)8796. Issue 1. September 2007

Scope

A significant proportion of this report summarises the geological conceptual model and the multitude of reviews of the hydrogeological model that have been undertaken since the 2002 PCSC was submitted and reviewed by the Environment Agency. The latter is particularly welcomed given the iterative nature of authorship; it would have been useful to consider adding a brief précis of this summary within the main text of Volume 4.

The development of the conceptual model advanced in parallel with the development of the version 1 site-scale model (Arthur *et al*., 2008a), however, the simulated heads from the numerical model did not agree well with the observed values. Further comments on the version 1 site-scale model are provided below.

Conceptual model development

The results of tritium monitoring are used in the development of the conceptual model for the upper groundwater system. It is argued that the distribution of tritium within the upper groundwater is driven by lateral migration due to a relatively lower vertical hydraulic conductivity punctuated by areas in which the material with lower vertical hydraulic conductivity is absent (thereby allowing the tritium to migrate vertically to a lower depth). The description of tritium contamination notes that fewer monitoring wells are located in the north-east, north-west and south-east of the LLWR site so the tritium plume is less delineated in these areas than in the south-west.

Furthermore, only limited advances have been made in conceptual understanding since the 2002 PCSC. The description of the conceptual model frequently refers to the 2002 PCSC as the basis for aspects of the model, as listed below:

(a) The thick slice geological cross-sections developed at a site-scale as part of the reinterpretation of the geology provided a new insight and identified features that could have significant implications on the hydrogeological model.

    This data has yet to be included in the updated conceptual model, but no reason is given for their omission, which we believe is a significant weakness in the breadth of the analysis.

(b) Little additional attention has been given to furthering the understanding of the tritium source term (e.g. location, timing) so that the time-series tritium monitoring data can be used more to further characterise groundwater flow pathways. The most recent monitoring data (Ruddick and Foster, 2007) is not referenced in the report.

    This shortcoming is considered to be an area of weakness for both the development of the conceptual model and for building confidence. It also displays a deficiency in general site understanding. The Environment Agency expects LLW Repository Ltd to be able to provide assurance of the radiological protection of the public and in doing so to have developed a sufficient understanding of the impact of current and previous activities to inform projections of potential future impacts.

(c) The consequences of the difficulties in interpreting groundwater head measurements as identified by Towler *et al.* (2007) do not seem to have been considered in the review of the conceptual model.

    The discussion in Section 2.3 on the findings of Towler *et al*. (2007) does not conclude anything other than a statement accepting that vertical gradients exist, which is then dismissed by a statement that *“whether groundwater is truly perched or whether there is a partially saturated zone above the water table probably makes little difference to the vertical travel time through the these strata.”* Whilst this may be true, it is not clear how the conceptual model covers this area (Figures 8 and 9 in the report are based on the 2002 PCSC interpretation). The site-scale numerical models are saturated so they cannot be used readily to provide support here.

(d) A lack of basic information on the level of the railway cutting and associated drainage features leads to an imprecise description within the conceptual model (and poor representation within the numerical models).

It is therefore disappointing to see a list of 10 improvement areas for the conceptual model as the final section of the report. Had the version 1 site-scale model that was concurrently being developed (Arthur *et al.*, 2008a) reached a more mature level, information from the model could have been used to help prioritise these areas within a forward programme of development work. Without such prioritisation or commitment to a forward programme confidence in the conceptual model presented is eroded.

Arthur, S., Sears, R. and Whitaker, D. A., 2008b. LLWR Lifetime Project: Version 1 Site-Scale Groundwater Flow and Transport Model. Nexia Solutions Report No. (07)8794. Issue 2. March 2008.

The stated purpose of the version 1 site-scale hydrogeological model is to develop further the hydrogeological understanding of the LLWR site (e.g. the development of a site-scale model, sensitivity studies, the scoping of a model for contaminant transport). The version 1 model was also developed to provide output for use in safety assessment models. The model apparently contains numerous simplifications. For example, the model has a reduced level of discretisation compared to the larger-scale regional model of Towler and McGarry (2007). It also assumes that the Quaternary sediments are planar (which is acknowledged as potentially being *"several metres discrepancy in some areas between the observed and modelled geology"*) and that lithofacies packages LP2 and LP3 are undivided at the site-scale. The concluding text contains the following self-evident remark: *"The development of the Version 1 site-scale groundwater model has shown the importance of correctly representing the permeability and the recharge mechanisms in achieving a satisfactory simulation of the groundwater flow processes at the LLWR site."* It is not clear that the report met its aims.

Henderson, E., Arthur, S., Sears, R. and Whitaker, D. A., 2008b. LLWR Lifetime Project: Version 2 Site-Scale Groundwater Flow and Transport Model. Nexia Solutions Report No. (07)9272. Issue 2. 20th August 2008.

Scope

A series of objectives for the version 2 site-scale model are included at the outset. It is noted that the version 2 model incorporates some changes that were not based on the findings of the version 1 model (e.g. the expansion of the model's area of coverage to incorporate the River Irt within the model rather than as a boundary condition).

Section 1.3 of the report refers to "'Version 2' 3D geology" and suggests that this three-dimensional geology from version 2 has been integrated in the groundwater flow model. It is not clear to what "'Version 2' 3D geology" refers, nor how it represents an improvement over the version 1 model, as the stratigraphic succession in both modelling studies appears to have been based on the same work.

Approach

Some previous observations on the limitations of the underlying conceptual model will not be repeated here. Our review has shown some significant limitations in the supporting analyses which have not been addressed in the submission. For example, the saline model work is used in Section 2.6.3 of this supporting document to describe the discharge of regional groundwater, but without mention of the early state of development of the model, the significant number of simplifications it contains or its reliance on a poorly calibrated regional model for support.

As noted previously, the domain for the version 2 model has been extended relative to version 1 and the number of layers has been increased from 9 to 16. The numbers of nodes and elements have more than quadrupled. The reasons for these changes (aside from the discretisation of LP1) are not given.

The reason for limiting the time range for the calibration and boundary data from 1995-1999 is not apparent, nor given. Given the long-term nature of the safety assessment calculations it would be expected that steady state modelling would taken account of long-term averages rather than the short-term data proposed here. Therefore we would expect an analysis to have been presented which undertook a comparison of the recharge and surface water discharges within the period 1995-1999 compared to the longer term. It would also have been relevant to note whether there had been any other activities on the site during this time that may have influenced the surface water hydrology and/or groundwater (e.g. change in land uses or drainage features).

The analysis of the tritium concentrations is hampered from its conception by the lack of a definition of the tritium source more precise than that *"the tritium source is considered to be the trenches".* The location of the majority of tritium disposed of is known because it has been determined from tipping records with a certain degree of accuracy. Section 3.2.3 of Volume 4 states that the source of the tritium contamination observed in the regional and upper groundwater *"is considered to be the Trenches, as discussed in Volume 3….[which] indicates that the disposal of Beta Lights between December 1983 and April 1994 to Trench 6 accounts for the majority of tritium in the trenches."* However, it is not clear whether LLW Repository Ltd believe that this relatively discrete area is the source of tritium observed within groundwater or that the tritium comes from another, more dispersed, source. It is noted that the tritium plots referred to in Section 2.7.1 of the report relate to a single year; they cannot therefore be used to discern potential migration pathways or release rates in order to identify or quantify sources. There is also significant uncertainty as to the past evolution of the flux over time. Without a clearly defined source term it is difficult to build confidence in either the direction of groundwater flow or migration rates described in the conceptual hydrogeology model and represented in the numerical models.

During calibration of the base case model, the decision was taken to vary the horizontal and vertical hydraulic conductivities of LP2/3 such that the 'standard' assumption of 10:1 anisotropy ratio was not honoured. On page 17 it is stated with regards to hydraulic conductivity that *"there is little difference between the different lithofacies packages"*, so we would therefore expect further justification to support the decision to retain a 10:1 anisotropy ratio for other lithofacies packages. Is it possible to achieve the required vertical gradients by reducing the vertical conductivity of other lithofacies packages, such as LP4? One of the advantages of using an automated calibration procedure such as PEST is that a relatively large range of parameter values can be considered within a calibration exercise. However, reasons are not given for restricting the calibration process so that the anisotropy ratio was only varied in LP2/3. It is not clear whether this parameterisation is believed to represent all four possible explanations made in Sears (2007) regarding the existence of vertical gradients or only one of them. If the latter, how will the other possibilities be assessed? Other potentially important geological information appears to have been ignored. For example, potential channel features were identified from the thick slice cross-sections; these features might suggest that hydraulic conductivity may not be the same in the x- and y-directions, as was assumed. Such additional information would build confidence in the level of agreement reached.

We observe that the model appears to have been developed without including ongoing work to assess *"the variability of the hydraulic conductivity of the superficial deposits".* It is not clear why this has occurred, or what this most recent study will add to the many, often contradictory studies, that have been reported in the supporting documents.

Results from the calibrated model

The acceptability of the modelled baseflow for the reach between Frog and Robin warrants closer analysis. The estimated baseflow used as a calibration target should also be reviewed. If the baseflow estimation for this reach is not well constrained then it is possible that the current value is also overestimated as opposed to under-estimated. Whether this representation is conservative for the post-closure period depends on how this representation influences the behaviour of the model once the engineered features at closure are included within the model.

There is sometimes a tendency in this report to present the model results as if they are reality, rather than a construct of it. For example, the elevated heads in the trenches in layer 1 are suggested to be caused by *"greater thicknesses or reduced permeability of clay-dominated layers (LP2)"*. However, it is not evident that the model is sufficiently sophisticated to include such representations because LP2 and LP3 are not distinguished at the site scale.

Given the absence of an uncertainty analysis within the study and the simplified approach to treating flow within the Quaternary sediments, some degree of caution should be exercised when the forward and reverse particle tracking is interpreted. It would be relevant for the interpretation to discuss whether hydrodynamic processes such as dispersion were included in the modelling; if not, the use of the results under these circumstances should be justified.

In interpreting the tritium transport model, the authors suggest that the dispersion plumes produced by the model are limitations in the numerical scheme. They do not consider that the source term may be too poorly defined to make the results credible. Similarly, when attempting to compare predictions of the tritium distribution through time, little consideration seems to have been given to the potential timing of disposals, the previous developments at the site (e.g. trench construction, interim cap emplacement) and the fact that the steady-state model was calibrated using boundary conditions and targets from 1995-1999. As noted previously, in Section 3.2.3 of Volume 4 it is stated that the source of the tritium contamination observed in the regional and upper groundwater *"is considered to be the Trenches, as discussed in Volume 3….[which] indicates that the disposal of Beta Lights between December 1983 and April 1984 to Trench 6 accounts for the majority of tritium in the trenches."* Therefore it is not apparent why a uniform distribution throughout the trenches was assumed, nor why simulations were started at 1955.

As noted previously, LLW Repository Ltd do not clearly describe the conceptual model of tritium release. The authors assume that this omission is acceptable during the early stages of the transport model's calibration, but this assumption ignores the fact that LLW Repository Ltd should be able to demonstrate an understanding of the mechanisms underlying tritium release and migration as part of their operational management of the site. As stated previously, this understanding should also be used to inform the development of the conceptual model for groundwater flow.

Future scenarios

The rationale behind the identification and description of Scenarios 1 to 5 – and how they link to the EPA (Paksy, 2008) and with general views on future performance – is not clearly presented. The source of the scenarios should have been presented and their links with the EPA and elicitation workshops should have been documented clearly.

Scenario 2 is purported to represent partially degraded engineered structures under the current climate. The cut-off wall and vertical drain are parameterised as "fully effective", therefore the cap is the only structure assumed to have partially degraded here. The reasoning for an intact cut-off wall and vertical drain is not clear, and we question whether the cap should be considered to be the structure with the largest chance of not achieving its design performance. We are also concerned that the vertical drain is assumed to remain fully effective. Furthermore, the timeframes for the applicability of the these scenarios should have been included in the analysis.

It is not clear whether any checks were undertaken on the model results for Scenarios 1 to 5 to confirm that the model configuration was producing an acceptable solution. We think such checks are particularly important because:

(a) the original calibration was across a relatively narrow time range,
(b) there is no accompanying sensitivity study for the simulations
(c) the mesh properties and boundary conditions (used to represent the closure engineering and changed boundary conditions) were altered.

It is suggested in Section 6.1 that the high heads to the south-west of the disposal area arise from the high topography in this area; however, the heads seem relatively insensitive to the large amounts of cap run-off that are predicted, especially in the area adjacent to the future vaults (and particularly in the case of Scenario 3). The conceptualisation of the infiltration of excess cap run-off and its representation within the model requires further explanation.

The interpretation of results relies heavily on simulations of particle tracking, but they are not supported by a thorough examination of their limitations and uncertainties. Given the limited scope of the simulations undertaken, such caveats should have been identified and discussed.

It is not clear why Scenario 5 does not consider a coastline that is closer to the site boundary within its configuration. This appears to be a significant omission from the calculation and, given that the scenario is stated to represent *"the maximum sea level rise that will occur prior to potential disruption"*, it must be assumed that the coastline would be relatively close to the site and so the length of the groundwater pathway would be shortened significantly.

Interface with GoldSim

It is noted that GoldSim uses 10 pipes to represent groundwater flow, compared to the 1.8 million elements of the FEFLOW model[7]. Numerical dispersion within the GoldSim model is not discussed,

[7] Obviously significantly fewer than 1,800,000 FEFLOW elements will represent the pathways from the disposal areas but there will be significantly more than the 10 used in GoldSim.

and no comparisons of estimated fluxes from the two models are provided, so it is difficult to be confident that the GoldSim representation was adequate.

The exclusion of horizontal transverse dispersion and the inclusion of vertical transverse dispersion represent a mixture of cautious and non-cautious assumptions. Such a mixture of assumptions may not be helpful when assessing whether the final calculations are cautious or not. No information was provided on the treatment of longitudinal dispersion within GoldSim. More generally, and linking to previous discussions on numerical dispersion, we find no information on the Peclet number assumed in the GoldSim calculations, nor how this relates to the estimates of dispersivity used within FEFLOW and derived from site-specific data.

From the configuration presented in Volume 4, it is unclear how pathways through a degraded cut-off wall may be represented within the model (including the potential for discharge to surface water). It seems that (rather optimistically) the model assumes that radionuclides can only leave the near field vertically downwards. It is not clear why it was considered inappropriate to extend the GoldSim model used in the EPA (Paksy, 2008) to the geosphere-biosphere interface, as this would have increased the level of consistency with the EPA.

Appendix C is missing from the version of the report sent to the Environment Agency.

Conclusions

The version 2 model represents an improvement over version 1, but there are still significant areas of uncertainty and further work is required to demonstrate that LLW Repository Ltd has both a conceptual and quantitative understanding of the site hydrogeology.

The value of the modelling studies to support the estimation of the site's performance under future conditions following closure is hampered by a number of weaknesses and simplifying assumptions in the approach to model development and calibration outlined above. These weaknesses are compounded by a negligible appraisal of the potential impact of uncertainty on the results.

Generally the areas identified in the report for further improvement suggest simply a need for more effort in modelling work and do not reflect the need for a more balanced approach which includes iteration of modelling with conceptual model development and supporting activities. For example, the fit between observed and modelled tritium could probably be improved by characterising the source term rather than purely focusing on modelling studies.

It is not clear whether the "Conclusions" section of the report aims to provide a complete list of all the areas of modelling work that require further attention. For example, it is disturbing to see that the development of a transient model is not included in the list.

Paksy, A., 2008. LLWR Lifetime Project: Near Field Engineering Performance. Nexia Solutions Report (08) 8275. Issue 03. June 2008.

Scope

The assessment timescale of the EPA starts at 2150 and it is suggested that *"the assumed state of engineered components"* at this time is the starting point for the assessment. It is not clear how the behaviour of engineered components from their time of emplacement up to 2150 is considered in developing views on their longer-term performance. For example, it is not apparent in the analysis of percolation through the cap whether the timings in Table 2 take into account the time that has elapsed since the emplacement of the cap.

The relationship between the 'site-scale groundwater flow model' and the 'performance of key components' in the EPA methodology is confusing; the former is regarded as an input and the latter an output, but their representation in Figure 1 suggests an iterative relationship.

Methodology

The proposed treatment of uncertainty is confusing. For example, it is stated that uncertainty *"in component performance and the resulting uncertainty in near-field flow volumes have been treated as parameter uncertainty to be explored in variant calculations"* and then (rather confusingly) that *"uncertainty in near-field flow regimes may be investigated later as part of alternative model analyses."* The near field flow 'volumes' and 'regimes' are not defined or explained; it is unclear whether the two reference cases and six variant calculations are taken to represent an assessment of uncertainty in both flow 'volumes' and 'regimes'. They are then later described *"as parameter uncertainties, or as conceptual model uncertainty, depending upon the range and complexity of the resulting flow regimes".*

The role of the vertical drain is another key aspect of the EPA, but it is not clearly presented. The presentation fails to discuss:

(a) the basis for determining the need for its inclusion (it is suggested to be a primary means of leachate management in one area, but elsewhere several "optional" vertical drains are referred to);
(b) the timing of its emplacement (it can only sensibly be installed before the final cap is placed over the vaults and it is not clear whether it requires the interim trench cap to be partially removed rather than *"at any point up to the end of the management phase"*);
(c) its performance envelope (it is assumed to provide *"sufficient capacity at all times"* whereas other components are parameterised with best estimates for lower and upper bound performance);
(d) the screening of uncontrolled overtopping (i.e. bathtubbing) on the basis of the inclusion.

We note that the estimates of infiltration rates through the cap are significantly below those currently estimated for the interim trench cap and also compared to those previously estimated within the 2002 PCSC. It seems that this change stems primarily from reduction in the estimated values of HER. Section 4.1 of the report states that *"substantial drying of the topsoil layer will occur in summer",* but Section 5.2 states that there is *"no significant soil moisture deficit"*. These statements are not necessarily contradictory, but we are concerned about the consistency of the statements with Appendix B of Henderson *et al*. (2008) which reports summer soil moisture deficits ranging from approximately 100 mm to 400 mm for the same climate states.

It is also not certain whether the elicited range of infiltration rates is consistent with Environment Agency guidance (Environment Agency, 2004). This guidance is referred to later in the report where it is suggested that the upper bound of cap infiltration may be the value of HER. The range selected may therefore be optimistic rather than representative of the potential envelope of performance. A secondary factor – protection due to vegetation – may also help to reduce rates of erosion. However, it is uncertain whether the vegetation considered will tolerate this moisture regime and whether deeper rooted vegetation, which may threaten the clay layer, could get established. Furthermore, the projected increases in the intensity and variability of rainfall under changed climate states could also be important factors affecting the potential rates of infiltration through the cap.

The analysis considers the spatial extent of slumping, but does not seem to consider the significance of the location at which the slumping could occur. Given the nature of the wasteform developed for disposal within the vault, it is likely that the most significant occurrences of slumping could occur within the cap covering the tumble-tipped and unconditioned wastes disposed in the trenches. The analysis justifies the adequacy of the infiltration estimates by considering the effects of slumping averaged over the entire cap surface area. However, it would be appropriate to also consider the localised effects of a high rate of infiltration within a rigorous assessment of uncertainties.

It is apparent that several simplifying assumptions have been made in the course of the EPA and the elicitation of supporting data. In several cases further justification for an assumption is required as well as a more detailed consideration of alternative assumptions, as detailed below:

(a) It is assumed that the Vault 8 concrete base cracks and so does not limit flow, which is taken to be a cautious assumption.

It is not apparent that such a preconception is necessarily valid because, for example, the duration of contact between groundwater and waste will be increased and the vertical drain may need to be used earlier than envisaged. It is also not certain that upper bound performance could not be defined as the base remaining intact without cracking.

(b) It is similarly assumed that the concrete base of any future vaults will crack, but here the bentonite is assumed to either remain intact or self-heal.

(c) Interpolation often assumes a *"linear rate of change over time in the logarithm of the hydraulic conductivity"*, but this is not justified, particularly in situations when component performance may evolve via a sudden failure mechanism (e.g. cracking).

(d) The timescales over which the permeability of the cut-off wall is interpolated is confused in Table 6: "0 to 1000" may be intended to read 500 to 1000 years. However, the reasoning behind a shorter period of time to reach the "at rest condition" for the upper and lower bound is not clear.

(e) Was the assumption of "sufficient capacity" for the vertical drain supported by the elicitation workshop? Why is it considered to be supported within the EPA?

(f) If the concrete base of any future vaults is assumed to crack, is it not possible that the side wall structures could fail following the failure of the base? Does the range of parameterisation reflect this?

We also question why it is considered justifiable not to disaggregate near field flows within the near field components, especially the trenches. Has the assumption that such flows are secondary to flows though the near field-geosphere interfaces been tested? It is possible that each of the trenches may maintain a different level of groundwater; it is also highly unlikely that leachate from within Trench 7 is able to flow into the vertical drain as readily as that in Trench 3. Similarly, based on Figure 2, it is most likely to be an exception (rather than the rule) that groundwater can flow from the "associated geology" to the vertical drain. As noted previously, the performance of components in other areas may also be highly variable, for example, areas of the cap that may be more prone to failure by mechanisms such as slumping. Is it considered impossible for contaminants to flow sideways out of the vertical drain given that it is un-lined and passes through heterogeneous strata.

The calculation cases that have been identified seem to have been based solely on combinations of pre-defined parameter ranges rather than by identifying the potential sequence of failures and degradation during the evolution of the engineered components and then attempting to represent these evolution scenarios.

Results

The configuration of GoldSim used to calculate the near field water balance requires further description, explanation and justification to support the adequacy of its use. Its relationship with the site-scale hydrogeological model implemented in FEFLOW (Henderson *et al*. 2008) requires further consideration because:

(a) it is not clear whether the purpose of the GoldSim model is to undertake simple calculations to route the near field flows between the various gates based on the site-scale hydrogeological model or whether it is an attempt to construct a process-level model capable of representing the major hydrological processes of interest within the near field;

(b) it is not apparent that the assumed independence of near field flows on the groundwater heads in the adjacent upper groundwater and regional groundwater systems is reasonable and justifiable;

(c) the spatial and temporal discretisation of the models is different (e.g. the site-scale hydrogeological model calculations comprise a series of steady-state simulations whereas GoldSim appears to consider time-dependent changes in parameters within a calculation).

Given the limitations identified above, it is not immediately apparent that the flows through the near field components are supported to a level adequate for the purposes of a quantitative safety assessment.

List of abbreviations

ALARA	As low as reasonably achievable
BGS	British Geological Survey
BNFL	British Nuclear Fuels plc
BNGSL	British Nuclear Group Sellafield Limited
Defra	Department for Environment, Food and Rural Affairs
DSCP	Drigg Site Characterisation Programme
EPA	Engineering performance assessment
ESC	Environmental safety case
GRA	Guidance on Requirements for Authorisation
HPA	Health Protection Agency
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IAF	Issue assessment form
ICRP	International Commission on Radiological Protection
ISO	International Organization for Standardization
LLW	Low level waste
LLWR	Low Level Waste Repository near Drigg, Cumbria
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
NII	Nuclear Installations Inspectorate
NRPB	National Radiological Protection Board
OESC	Operational environmental safety case
PBO	Parent body organisation
PCSC	Post-closure safety case
PEG	Potentially exposed group
R&D	Research and development
RSA 93	Radioactive Substances Act 1993 (as amended)
SLC	Site licence company
UKAEA	United Kingdom Atomic Energy Authority
UKNWM	United Kingdom Nuclear Waste Management Ltd

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