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

Technical Review of Volume 3: Inventory and near field

NWAT/LLWR/09/003 [Sector Code]

Contents

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1 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).

[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 an 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 3: Inventory and near field.

2 Review of Volume 3 and key supporting documents

2.1 General

2.1.1 Overall, we found that Volume 3 presents a useful, coherent overview of developments in relation to the inventory and near field. The report generally makes reference to suitable reports and data to underpin its findings.

2.1.2 We note the point, emphasised in this volume and elsewhere, that Volume 3 is not intended to present a full environmental safety case (ESC). Nevertheless, we take the view that this submission presents a good opportunity for us to review and comment on LLW Repository Ltd's progress towards a full ESC (due by May 2011). We have therefore included comments of this nature, but we have aimed to distinguish clearly between our conclusions (and any pursuant regulatory decisions) that relate to the submission as a response to Requirement 2, and our recommendations on issues that LLW Repository Ltd should consider in their work towards an updated ESC.

2.2 Design of the LLWR

2.2.1 Chapter 2 of Volume 3 provides an overview of the design of the near field, beginning with a description of the site in its current state and plans for seven additional vaults. The bulk of Chapter 2 describes near field engineering and the current plans for the proposed design and emplacement of engineering structures during the management phase, post 2050, and hence to site closure.

2.2.2 The description of the wastes and waste forms is based on waste treatment and conditioning practice to date. We are aware of initiatives to apply more rigorous segregation techniques, to investigate alternative designs for containers and to consider the possibility of pre-treating (e.g. incinerating) future wastes. The discussion throughout Volume 3 (and through Volumes 1–5 in general) does not mention these possible changes. We consider that such possibilities should at least have been noted, with an overview of their potential implications for the safety case. We accept that at the time the Requirement 2 submission was being compiled these new initiatives were only being developed and written into future Lifetime Plans, so we would not have expected in depth analyses.

2.2.3 The proposed site engineering design, termed the "Single Option", is outlined in Section 2.3 of Volume 3 and its performance is discussed in Chapter 6. We note, with respect to vertical drains, that these are, "*optional and of different design (location, type and plan area) in the Single Option*". However, in deriving the near field flow field the performance of the "optional" vertical drain(s) is assumed to provide "*sufficient capacity at all times*", acting as a sink for any flows arising from controlled overtopping (Gate 5). We return to this issue in Section 2.6 of this review.

2.3 2002 PCSC near field and inventory

2.3.1 Chapter 3 of Volume 3 provides a factual summary of work reported in the 2002 PCSC.

2.3.2 The arguments regarding near field evolution are reasonable in broad terms (e.g. establishment of reducing conditions due to degradation of organic material and metal corrosion, the establishment of hyperalkaline conditions in the vaults). We note, however, that a number of detailed issues were raised in our review of the 2002 PCSC and these remain unresolved. As a general point, and as discussed further below, we note that any arguments based on the 2002 near field understanding will also be subject to these remaining issues if they remain unresolved as the case develops.

2.3.3 Volume 3 acknowledges that the projected evolution of the near field (as per the 2002 case) will change as understanding about the site (e.g. better knowledge about the inventory) and proposed engineering develops over time. These changes might have an impact on related safety case arguments. For example, changes to the non-radiological inventory and near field groundwater flows will influence the projected chemical backdrop derived from the DRINK (DRIgg Near Field Kinetic) model; adjustments to these derived parameters would alter the projected timescales over which reducing conditions pertain and the projected "pseudo-solubilities" of C-14. Such changes may be more or less significant, depending on the future case that is presented, and any related arguments. We expect a suitable appraisal of such aspects in the 2011 ESC.

2.3.4 The discussion of coastal erosion, which is expected to "*result in destruction of the site between 750 and 2500 years*" acknowledges that evolution of the near field may be impacted through changes to the landscape and the hydrogeological regime. It seems possible that erosive ingress into the site might enable reoxidation prior to the site's complete destruction (e.g. facilitated by the ingress of more oxidising waters through breaches in engineering features such as cut off walls and the cap). Should this occur, there may be a period during which contaminated drainage from the reoxidising site emerges into the accessible environment. We believe that such a scenario, and others that might be relevant as the site is encroached, should be covered in the safety case.

2.4 Updates to inventory

2.4.1 Chapter 4 of Volume 3 provides an update on the site's inventory. It outlines areas where LLW Repository Ltd believes it has improved its understanding of the inventory, describes the methodology for deriving the inventory from documentation and summarises significant changes in understanding since the 2002 case.

2.4.2 Significant changes have been made to the assumed distribution and form of the uranium inventory, which is now thought to be roughly half that assigned previously to the trenches and roughly double that assigned to the vaults in the 2002 case. The C-14 inventory has been notably reduced. We note that decay products of uranium in the trenches provided the source of the peak projected risks in the groundwater pathway in the 2002 PCSC. Likewise, risks arising from C-14 in the gas pathway provided some of the highest risk projections in the previous assessment. Clearly, an equivalent analysis would suggest that the reduced inventories of these key risk-determining radionuclides would lower the long-term risks associated with the site. We also note that a number of radionuclides, such as Np-237, are assigned a considerably higher inventory relative to the 2002 case.

2.4.3 The significant revision of the inventory relative to the 2002 inventory highlights the inherent uncertainty in the inventory appraisals. However, any detailed discussion of uncertainty is notably absent, with no reference to the confidence bounds on the inventory data nor a discussion on the projected risks if such uncertainties are propagated through the assessment. We have noted various examples where the treatment of uncertainty is extremely limited throughout the response to Schedule 9 Requirement 2.

2.4.4 The inventory assigned to the trenches is now defined at the disposal bay level. This work was based on a hierarchy of inventory data sources for the trenches as outlined in Table 4.1 of Volume 3. The submission develops arguments regarding the spatial distribution of uranium and its form, to support arguments about the uranium source term, as discussed further below (Section 2.5). The refined inventory data is also used to support arguments regarding site optimisation, as described in Volume 2 (LLW Repository Ltd (2008a)).

2.4.5 We note that significant proportions of the inventories of certain radionuclides are attributed to a small number of specific wastes streams that are yet to be disposed to future vaults (e.g. Np-237, C-14). In the case of C-14, for example, we note that "*Approximately 98% of*

C-14 at the LLWR will be present in the future vaults (Figure 4.2)" and "*the total predicted activity of 7.5 TBq for C-14 would not be acceptable under current disposal limits, and it is possible that alternative solutions will be found for its disposal*."

2.4.6 We agree that *"the identification of significant future waste streams and waste types, such as the large quantities of contaminated soil scheduled for disposal at the LLWR, provides important information that could be used by the LLWR when considering the future use of the remaining disposal capacity of the site."*

2.4.7 The assumptions about inventory distribution in the future vaults are based on conditioning practice to date. We are aware of initiatives to apply more rigorous segregation techniques and to consider alternative container designs and possible waste pre-treatments (e.g. incineration). These techniques may change the form of the conditioned waste for disposal, the concentration of radionuclides and the volume of the waste (thus the rate at which a vault's capacity is used). Any such developments might alter the site safety case (e.g. doses arising from intrusion will essentially scale with the concentration of the dose-determining radionuclides). We recommend that such possibilities are analysed in relation to both site optimisation and in the development of the ESC.

2.4.8 Further to the above we suggest that LLW Repository Ltd could usefully develop a methodology for assessing key waste streams and their associated impacts through the site performance assessment. This approach would identify those components of the projected inventory that are likely to present specific challenges. This would be particularly important if the site's waste acceptance criteria and/or the nature of the wastes to be disposed at the site were to be changed. This information could also feed into and support the developing national LLW strategy and measures to improve the national inventory and confidence in it.

2.5 Near field behaviour

2.5.1 We agree with the statement that "*some modification of our understanding of the biogeochemical evolution of the site may be required before the submission of the full 2011 Environmental Safety Case.*" We add, as per para. 2.3.3 above, that any arguments based on the 2002 model of the near field are subject to the unresolved issues that we have previously raised and which are yet to be addressed.

2.5.2 Perhaps the key development (relative to 2002) relates to the form and distribution of uranium disposals in the trenches and the conceptual model used to describe uranium release from such wastes to the groundwater pathway. It is estimated in the submission that 95% of the trench uranium inventory comprises residues from the Springfields site that consist of filter cake residues (insoluble silicate material) and magnesium and calcium fluoride residues. The conceptual model assumes that kinetically moderated dissolution of the residue matrix enables the uranium to be released in proportion to its mole fraction within the residues.

2.5.3 The factors that would give rise to risks exceeding the 10^{-6} y^{-1} risk target, based on the 2002 PCSC assessment of the groundwater pathway, are discussed in Volume 3 (p. 35-36). These factors include a dissolved uranium concentration from the trench inventory exceeding 10^{-6} mol/L. The submission presents arguments that residue leaching could lead to a concentration of dissolved uranium from the trench inventory below 10^{-6} mol/L, and therefore to correspondingly lower risks.

Uranium leaching model

2.5.4 The uranium leaching model, as developed and parameterised to date within the Requirement 2 submission, is used to argue that uranium concentrations of around 10^{-7} mol/L will develop in the leachate (p. 37 of Volume 3; Figure 10 in Small *et al*., 2008). This calculation is based on the assumption that the residue contains 0.1% (by weight) uranium. To explain certain site monitoring data the submission also argues that uranium concentrations exceeding $10^{-5.5}$ mol/kgw may arise from the leaching of more soluble residues. Given some of the uncertainties outlined below (e.g. the rate of residue dissolution, the nature of the residues and their uranium content[4]), we consider that there is considerable scope for sensitivity analysis. This has been recognised in the work presented to us (Section 7 in Small *et al.*, 2008) and we expect to see further work in this area if the leaching model is deployed in the full ESC.

2.5.5 It is argued that observed, elevated fluoride concentrations in trench geosphere boreholes are consistent with recorded disposals and subsequent leaching of uranium-bearing fluoride residues. We find the conceptual model and its representation to be reasonable, but in need of greater substantiation if it is to be developed further for deployment in support of the full ESC. In particular we note the following:

(a) Whilst the model is not inconsistent with site monitoring data, the argument that "*the model has been given convincing support through consideration of site monitoring data*" is perhaps an overstatement.

For example, previously it was argued that site monitoring data (e.g. dissolved uranium concentrations) are consistent with an alternative model describing uranium release (Small *et al.*, 2005). This latter comparison illustrates that there are alternative explanations to account for the dissolved uranium, calcium and magnesium concentrations. It is difficult to draw any firm conclusions from the log-log cross plots presented in Figure 5.2 (in Volume 3): the trend line relating to a Mg:F ratio of 1:2 is just one interpretation of the data scatter. Likewise, the uranium concentration data presented in Figure 5.3 reveals only partial agreement, although we agree that the data trends are not inconsistent with the modelling work.

(b) Clearly the conceptual model and its parameterisation for assessment purposes provide only a simplified representation of a complex system and this is acknowledged in Volume 3.

However the description of the model does not explore or scope some of the underlying assumptions and simplifications, some of which are identified in a supporting reference (See Section 4.3.1 of Small and Thompson (2008)).

2.5.6 A number of detailed assumptions within the conceptual model and its representation are open to challenge; they do not appear to be supported by relevant experimental data or other lines of evidence. We would note the following aspects in particular:

(a) Arguments that uranium is released from the residues in proportion to its mole fraction may not be robust, particularly where the uranium is present within discrete phases rather than within the fluoride lattice.

We note, for example, that exposed uranium "shot" within the fluoride matrix is likely to have a differing solubility and dissolution rate to the fluoride residue matrix. The residues may vary in terms of the uranium content, both within and between trenches, and at various scales.

(b) The dissolution rate of the fluoride residue matrix is based on literature data derived from experiments with the mineral fluorite (CaF_2), as investigated by Zhang *et al*. (2006).

We note that the data provided by Zhang *et al*. (2006) relate to one specific mineral and its dissolution under a limited range of experimental conditions (pH 2.57–5.08, temperatures of 25° and 100° C).

2.5.7 It is widely known that dissolution rates of solids can vary significantly as a function of the composition, crystallinity and environmental parameters such as temperature and the composition of the aqueous fluid (e.g. pH, presence of species that can catalyse or inhibit dissolution). This effect of other species is well illustrated by the arguments developed in Volume 3, which suggest that measured fluoride concentrations in site groundwaters may exceed the predicted solubilities of magnesium and calcium fluorides because zinc (or other metal) fluorides could be present. We also note that the nature of the fluoride residues varies significantly[4], so a single dissolution rate may not truly reflect the complexity of the real system (Small and Thompson, 2008).

2.5.8 In the light of such uncertainty, which does not appear to have been fully appraised to date, it is difficult to conclude with confidence whether the residue leaching process will have a positive or negative impact on the risk projections for the groundwater pathway presented in 2002. We note, for example, the statement that *"the rate of release of the majority of uranium from the trenches could be several orders of magnitude lower than previously modelled"*. We would agree with this statement, but conclude that it is difficult to draw any firm conclusions as to the likely rate of uranium release from the trenches, based on the residue leaching arguments and evidence presented to date.

2.5.9 Overall, we believe that LLW Repository Ltd's approach to the representation of uranium leaching from recorded residue disposals adds to site understanding. Should uranium leaching from the trench disposals prove important to future ESC arguments, and if such arguments are to be developed further, we would expect to see additional work to address the issues we identify above. Others have noted that "*Further confirmation and justification of the model through research will therefore be important to the next safety case*" (Small and Thompson, 2008). We also note from Volume 3 that "*further work could readily be done to further justify these assumptions, should uranium leaching behaviour prove important for the groundwater pathway*" (p. 38).

Vault biogeochemistry

2.5.10 The description of vault biogeochemistry (Section 5.3 of Volume 3) suggests that the 2002 PCSC indicated that "*alkaline conditions would prevail for 10,000 years"* (p. 41 of Volume 3). We note that the 2002 PCSC suggested that vault alkalinity would be progressively lost from approximately 5,000 years onwards in the predominant direction of groundwater flow; the final wash out of cement was expected to occur some time after 10,000 years (BNFL, 2002b).

2.5.11 We also note that the modelling of the near field flow field in the 2002 PCSC projected the transfer of much of the trench uranium inventory to the vaults, where it would subsequently precipitate prior to final wash out. We anticipate that this process would reduce the projected radiological impacts of trench-derived uranium in the groundwater pathway, given the lower mobility of uranium within the vault environment (according to the 2002 PCSC). The conceptual model described in Volume 3 does not envisage trench-to-vault transfers of uranium because the trench and vault systems are assumed to be hydrogeologically distinct and the trench uranium inventory is now assumed to be relatively immobile.

2.5.12 Further work has considered heterogeneity within the vault system based on finer scale modelling of the vault disposal system (Kwong *et al.*, 2008). Based on this analysis, the submission argues that cement phases, represented by calcium silicate hydrate (CSH), will be present for a total of 2,600 years as a 2 m block. We note the arguments regarding the inherent conservative assumptions in relation to cement carbonation and upscaling in this modelling work.

2.5.13 Data plots of output from the model show only five years of vault evolution; it is unclear why data for the more evolved systems were not provided. It is unclear, based on what is presented by Kwong *et al.* (2008), whether CSH will persist throughout the modelled domain, or would be fully depleted at local scales over the 2,600 year timescale. Figure 25 in Kwong *et al.* (2008) suggests that in systems with low CSH, regions depleted of CSH will coalesce over short timescales (a few years).

2.5.14 Kwong *et al.* (2008) note that, "*CSH shows dissolution in the first 0.2 m of the grout over a 10 year period*", suggesting that the model predicts progressive removal of CSH at a local

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[4] See for example, "*CaF_2 has been described as being present as five distinct coloured phases, which have varying uranium contents. Red and smoky varieties contain relatively high uranium contents (7-15%) but yellow and white varieties have lower U contents (0.19, 0.68%)*", and that "*… some higher uranium concentration residues (<0.9 wt% uranium) could arise*" (p. 20, Small and Thompson, 2008).

scale over relatively short timescales. Based on Figure 24 (Kwong *et al.*, 2008), the average concentration of CSH decreases over 10 years from 9.4 mol CSH kgw^{-1} to an average of approximately 9.1 mol CSH kgw^{-1} (i.e. loss of around 0.3 mol CSH kgw^{-1} in 10 years). Assuming that this decrease continued at a linear rate[5] it would take about 300 years for complete CSH removal. On the basis of Figure 24, we therefore question the validity of the statement that "*Based on the average concentration of CSH dissolved over each time step during this 10 year period, a total of around 2,600 years would be required to dissolve the CSH from this 2m block of cemented waste form*."

2.5.15 Based on such observations, we question whether the modelling work fully supports the arguments for a prolonged hyperalkaline, cementitious near field vault environment, particularly at local scales. We return to this issue in the discussion of the representation of the near field within assessment models (see para. 2.7.3 of this report).

2.5.16 A comparison of LLW Repository's arguments with the Phased Geological Repository Concept (PGRC) (Nirex, 2005) is perhaps useful. Credit is not taken in the PGRC for the cementitious component of the conditioned waste form: it is envisaged that large quantities of cement-based backfill will be added to the disposal vaults[6] to compensate for any challenge to the hyperalkalinity of the system that is presented by the conditioned waste (e.g. through production of acidic species such as CO_2 and organic degradation species). It is our understanding that the ratio of grout to waste within waste packages would typically be somewhat lower in the LLWR than in the PGRC, and that (according to the engineering design of the LLWR) the space between containers is to be filled with an "aggregate fill"[7]. Therefore, less of the repository volume overall will be occupied by cementitious materials relative to the PGRC. While we recognise that the PGRC is designed to maintain alkalinity for a much longer period of time, this comparison reinforces our view that the evidence for assuming persisting hyperalkalinity in the LLWR vaults needs to be strengthened (if the assumption is important to the ESC).

2.5.17 We further observe that any future initiatives to increase waste incorporation might also increase the ratio of waste to cement (this observation is also relevant to the earlier discussions in para. 2.2.2 of this review). The higher proportion of waste could decrease the long term pH buffering capacity of the vaults, due to a lower proportion of cement within the conditioned waste and within the combined disposal volume overall. The assumption that hyperalkaline conditions will persist could be further challenged in such cases.

2.5.18 We note the arguments regarding the potential influence of the superplasticiser Sikament 10 on radionuclide mobility (Trivedi *et al.*, 2008). We are aware that the use of this reagent in cement formulations for ILW conditioning has not been endorsed through the Letter of Compliance (LoC) process. The NDA/RWMD have hesitated from endorsing this reagent because experimental studies with free solutions of the compound have found that it enhances radionuclide solubility. The arguments in Volume 3 conclude that the effect of the superplasticiser on radionuclide mobility will be small, which is one interpretation of the data, but also the least conservative approach with respect to treatment of the groundwater pathway.

2.5.19 Early disruption of the cement matrix by carbonation and leaching might accelerate solubilisation of the superplasticiser. We feel that any future safety case should investigate the sensitivity of radionuclide mobility to the potential effects of the superplasticiser Sikament 10. This work might be accomplished through appropriate solubility and sorption sensitivity studies.

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[5] In fact, based on Figure 24 (Kwong et al., 2008), the rate of CSH removal increases between successive years and if that trend continued then the timescales to depletion would be even shorter.

[6] For example, peripheral backfill is included in the generic design to a thickness of 0.5 m for all vaults. This backfill is additional to the local backfill that is emplaced in the spaces between and around waste packages (Nirex, 2003b).

[7] We recognise that preferential flows through the aggregate fill could reduce the amount of water flowing through the waste form. However, it is possible that the aggregate could clog. For example, precipitation of carbonate within the aggregate fill might lead to progressive sealing of any such preferential flow paths.

2.5.20 Work reported by Kwong *et al.* (2008) has found that uranium roll fronts could potentially develop within the trench near field, which may act to further retard uranium release to the groundwater pathway relative to that assumed in the 2002 PCSC. We note that this is work in progress and that numerical oscillations having been observed in the results of modelling of redox potential (Eh) against time, suggesting some instability in a key parameter of the model during these model realisations.

2.5.21 It is unclear how the proposed temporally and spatially discrete redox fronts would impact upon the predominant uranium source term[8] from fluoride residues. It seems technically plausible that redox fronts, and hence uranium roll fonts, might develop, but we find this is potentially inconsistent with the assumption that the trenches will remain essentially unsaturated based on the best estimate near field flow model. This issue is discussed further in paras 2.6.6–2.6.8 of this report.

2.5.22 Further work on colloids and the formation of organic complexes has concluded that "*organic macromolecules are unlikely to have a significant effect on near field solubility and sorption of uranium*" (p. 45) and with respect to inorganic colloids that "*their effects in subsequent assessment may not be warranted.*" These conclusions are consistent with the findings of the Review Group (Galson Sciences Ltd, 2004), which agreed that the impact of "*radionuclides associated with inorganic colloids and organics in the geosphere is likely to be minimal, and that any uncertainty associated with this assumption is encapsulated within the uncertainty runs carried out by BNFL.*"

2.5.23 We note that significant quantities of alpha activity associated with colloidal material in trench standpipes and boreholes have been previously identified (BNFL, 2002b). We question the validity of the assertion that such colloidal species "*do not appear to be stable within the geosphere environment*" (Volume 3, p. 46). Whilst there may be evidence that "*near-field colloids may not be stable when migrating from an anaerobic to aerobic environment*" (Trivedi *et al.*, 2008), there may be scenarios in which colloidal material does not encounter a redox front and hence remains stable for migration. Migration of such species within the near field and outward into the geosphere in reducing groundwaters cannot be ruled out, based on what has been presented to date. An example scenario of this phenomenon might be trench colloids migrating through a future vertical drain into the regional groundwater.

2.5.24 We acknowledge that a further desk study has been undertaken to "*Conduct further research into radionuclide-fulvic acid stability constants, dissociation kinetics, and models (including PA) incorporating these parameters*". This work has concluded that complexation of uranium with natural organic material (fulvic acids) is unlikely to be significant, although it is based on a simplified model of a potentially complex system.

2.5.25 We note that "*The potential for cementitious conditions to generate silica and iron based colloids in a deep disposal environment is well documented (e.g. Swanton et al., 2000). However there is no evidence for or against the possibility of the generation of LLWR vault facility derived colloids*" (Trivedi *et al.*, 2008). In the absence of firm evidence to refute the presence of vault derived colloids, however, we expect the possibility of a vault colloid source term to be covered in the full ESC. We note that the research proposed by Trivedi *et al.* (2008) might help to improve understanding of colloidal materials.

2.5.26 According to current understanding, "*The potential for colloids and organic complexation to increase the mobility of radionuclides within the near field has been assessed as low*". We also note the statement that "*Modelling studies show that the impact of inorganic colloids on risk was within the range of other uncertainties considered by the 2002 PCSC (Trivedi et al., 2008) and as such are not considered in the assessment*." We would not fundamentally disagree with this; however, we expect a suitable appraisal of any potential

[8] Based on the conceptual model describing uranium release from fluoride residues the local groundwater redox would only influence that fraction of the uranium inventory exposed to groundwater at a given time. Depending on the relative rates of release from the matrix and the temporal progress of any roll fronts this may or may not have an effect on the uranium source term from the fluoride residues inventory.

colloidal transport phenomena in the forthcoming ESC, and expect arguments to be substantiated by suitable sorption and solubility sensitivity studies.

2.6 Engineering performance assessment

2.6.1 A vertical drain is included in the engineering reference design. Its intended role is to "*minimise the likelihood of uncontrolled overtopping (or bathtubbing)*". We noted in para. 2.2.3 of this report (above) that the vertical drain is described as "optional" (p. 14) but that the vertical drain is assumed to operate with "*sufficient capacity at all times*" in the engineering performance assessment as presented in Volume 3 (Table 6.1, p. 49).

2.6.2 It is stated that "*vertical drains could degrade or clog*". Work presented in the 2002 safety case suggested that the performance of the vertical drain, as then envisaged, would decline after "*about 100 years, with a reduction in approximately two orders of magnitude in hydraulic conductivity*" (Volume 3, p. 51).

2.6.3 We recognise that site engineering is a matter for optimisation, but it is important that any assumptions about the performance of engineered features which are used in support of the ESC are based on realistic and achievable performance. We note that the engineering performance assessment, as presented in Volume 3, assumes that performance of both the cap and the vertical drain are sufficient to prevent bathtubbing. We expect to see in the ESC an appraisal of any impacts that might arise should future assessments of the facility's engineering performance suggest that "bathtubbing" might occur, and for any situations where such possibilities cannot be ruled out.

2.6.4 We note the assumption that the cut-off wall (a cement bentonite slurry) will degrade over 500 years, with a consequent increase in hydraulic conductivity. In contrast, the performance of the base of the future vault is assumed to remain constant over time. Although there are significant differences between the designs of the cut-off wall and vault base, we question the assumption that one can retain its performance indefinitely, whilst the other degrades over a period of centuries, especially as both structures have bentonite components that may be impacted by hyperalkaline fluids. We agree that it is not unreasonable, however, to assume that the bentonite component of the vault base would remain less conductive than the geology.

2.6.5 We note that "*The 'associated geology' was assumed to be identical to the natural geology featured in the supporting site-scale groundwater flow model (Volume 4). These values are 2E-9 ms^{-1} for vertical and 1E-5 ms^{-1} for lateral hydraulic conductivity (Paksy, 2008)*". We could not find a documented case with such hydraulic conductivities reported in Volume 4. The only reported vertical hydraulic conductivity of 2E-9 ms^{-1} was accompanied by lateral hydraulic conductivities of 7.5E-5 ms^{-1} (Volume 4, Table 5.3 Calibrated model parameters, p. 57). Based on this observation, we query whether the elicited values reported by Paksy *et al.* (2008) have been replaced by alternative values for modelling purposes and, if so, the reasoning behind this.

2.6.6 A "key finding" of the near field water balance model is that the trenches "*will remain unsaturated throughout the assessment period*"; this finding is in contrast to assumptions made in the 2002 safety case where it was assumed that the trenches would be at least partially saturated. We note that the DRINK model used to predict the trench near field evolution and the biogeochemical backdrop is based largely on the assumption of a saturated system[9].

2.6.7 The assumption of a saturated environment to represent a system that is expected to remain unsaturated is likely to be conservative with respect to the groundwater pathway, given that groundwater flow is required to provide a transport vector. If the "best estimate" projection of the trench near field environment is for an unsaturated system, then it may be

[9] We are aware that leaching and slumping of waste was represented in the DRINK model. Such transport mechanisms resulted in radionuclide transfer to the saturated zone and thence consideration within a saturated environment.

appropriate to revise the modelling approach to reflect better the expected conditions. At least any conservatisms related to the use of a saturated environment for the modelling should be explored and scoped. We are aware, for example, that the output of experimental lysimeter studies was used in the DRINK model to represent release from the unsaturated trench environment to the underlying saturated zone (BNFL, 1999).

2.6.8 This issue of the level of saturation is particularly important if the biogeochemical backdrops provided by the DRINK model are to be used in support of any simplified assessment models in the future. We recognise that such aspects, together with the significance of the leaching mechanism for uranium residue from the trenches, will be of greater or lesser importance in the future ESC depending on the significance of the groundwater pathway to the case.

2.6.9 There is no discussion of the design or performance of gas vents in Volume 3, although these are illustrated schematically in Figure 2.3 of the submission. Presumably these vents will enable gas release through the otherwise (essentially) impermeable cap. We would expect some appraisal of the performance of the gas vents and their possible influence on the performance of the cap as a hydraulic barrier. For example, presumably, following degradation, gas vents could act as rainwater conduits and thus increase the hydraulically effective rainfall. It would be useful to explore how the design and performance of gas vents might impact upon the assumed performance of the site cap. If, on the other hand, the "gas vents" are of such a nature that these possibilities are not considered plausible, this should be explained (**Category D recommendation** – see para. 1.5.4).

2.6.10 The near field flow model has been implemented in GoldSim, which has the functionality to use probabilistic data ranges for input parameters. It is our understanding that such an approach has not been adopted to date, although it may prove useful in future studies. For example, elicited data ranges could be provided for volumetric flows and hydraulic conductivities, although we understand that elicitation to date has been based on best estimate and bounding case assumptions.

2.7 Representation of the near field within the assessment model

2.7.1 We note that a simplified analysis of 'features, events and processes' (FEP) is proposed for future assessments (relative to the 2002 case). We do not disagree in principle with the proposed, simplified approach, but it is important that any FEP analysis is suitably comprehensive to support definitions of conceptual models and to provide a systematic framework against which uncertainties in modelling can be identified and assessed.

2.7.2 The discussion of the assessment time period is based on the assumption that gross disruption will occur within 5,000 years, hence risk projections beyond such times are not reported. The peak risks via the groundwater pathway projected in the 2002 safety case occurred at much later time points (the peak risks were mainly linked to impacts arising from U-234 daughters following site reoxidation). Given the uncertainties as to the timing and extent of gross disruption we feel that it would have been helpful to include assessments that extend out to the timescales of peak risk.

2.7.3 As per para. 2.1.3 of this review, we note that changes to the non-radiological inventory and near field groundwater flows might be expected to influence the projected biogeochemical evolution of the site (relative to the 2002 PCSC). It is not entirely clear that the additional work conducted in this area has fully substantiated the assertion that the broad characteristics defined in the bullet points (Volume 3, p. 58) remain valid. For example:

(a) Arguments have been made that trenches will remain essentially unsaturated. Assuming that this is the case, would the trench environment evolve through a reducing phase with subsequent reoxidation within 4,000 years?

(b) As discussed in para. 2.4.4 (above), based on the detailed modelling work provided to date, it is not entirely clear that the assumption of high pH conditions within the vaults throughout the assessment period is robust.

The "broad characteristics" of the conditions ascribed to the trenches and vaults are not unreasonable. Given the uncertainties, however, we consider that sensitivity to alternative evolutions (e.g. lower pH environments in some or all of the vaults at later times) should be investigated.

2.7.4 Volume 3 does not describe in detail how solubility control in the vault environment is represented. The performance update presented in Volume 5 indicates that, "*Based on results from the 2002 PCSC (Subsection 6.5.1 of BNFL, 2002c), only thorium, uranium and carbon have been treated as solubility limited*."

2.7.5 The projected solubility of uranium, based on the solubility of $CaUO_4$ in a cementitious environment (as per Table 7.1, p. 60), can be compared with the representation of uranium solubility in the Generic Performance Assessment (GPA) of the PGRC (Nirex, 2003), which is also a cementitious disposal concept. In the 2002 DRINK model $CaUO_4$ precipitation in the vaults was assumed to limit uranium solubility to around 10^{-8} mol/L (BNFL, 2002b; Kwong *et al.*, 2008). Sensitivity analyses considered solubility values that either increased or decreased this solubility limit by a factor of 10. In contrast, the elicited uranium solubility range considered in the PGRC ranged from 10^{-11} to 10^{-2} mol/L, with a probability of only 0.5 that the value will be less than 10^{-7} mol/L. The range is extended still further in the GPA through consideration of solubility enhancement in the presence of co-disposed organic species and their degradation products.

2.7.6 Based on our comparison with the data elicited by Nirex, we question whether the projected solubility of uranium in the LLWR vaults is conservative. We reach this conclusion even if we account for the potential differences between the environments of the disposal systems (e.g. potential differences in the long-term redox, pH and ambient temperature). The projected uranium solubility used by the LLWR is towards the lower end of the very wide distribution used by Nirex. The Nirex solubility data were derived through an expert elicitation process, which takes account of experimental evidence, published literature and expert opinion.

2.7.7 We would recommend that LLW Repository Ltd investigate how they can best derive and present in a transparent manner solubility data and associated data ranges for key radionuclides. We also suggest they review the validity of related assumptions based on the output of the DRINK model. We note that the DRINK approach and any expert elicitation process might prove complementary. For example, chemical backdrops projected by the DRINK model could provide quantitative estimates of the spatial and temporal extent of particular geochemical conditions, which are then used in the elicitation process and to build confidence in any resulting PDFs.

2.7.8 Further to para 2.2.3, we note that the "pseudo-solubility" of C-14 has been derived from the aqueous concentrations calculated within the 2002 PCSC DRINK near field model. The validity of any such "pseudo-solubilities" comes into question in the context of a changed inventory (radiological and non-radiological) and flow field. We would expect any values of "pseudo-solubility" to be suitably justified if such an assessment approach is to be pursued in the full ESC.

2.7.9 Further to paras 2.5.2–2.5.9, the proposed representation of uranium release from the trenches to the groundwater pathway (described in the bullet points on p. 61 of Volume 3) is based on a kinetic source term model that remains largely unsubstantiated. It is also based on arguments regarding differences in the disposed inventory (e.g. nature of residues), which are based partly on circumstantial evidence from local concentrations of uranium and fluoride in site leachate. The model, as presented to date, has been calibrated to an extent using site data. The approach does not seem unreasonable, but we expect further substantiation and underpinning, however, if these arguments and approaches are to be developed further.

3 Conclusions in relation to Schedule 9 Requirement 2

3.0.1 The response to Schedule 9 Requirement 2 is summarised directly in Volume 1 and our overall conclusions regarding the response to Schedule 9 Requirement 2 are provided in the Overview document of our review (Environment Agency 2009a).

3.0.2 We conclude overall that the work presented in Volume 3 provides a useful input to the Schedule 9 Requirement 2 and supports our view that the requirement has been substantially satisfied.

3.1 Work on inventory

3.1.1 In our opinion the work presented on inventory represents a useful refinement of earlier inventory work; it provides improved, detailed inventory data and better information on the spatial distribution of specific waste streams at the site. Volume 3 does not address the issue of the site's radiological capacity directly, which is covered in Volume 5, although the inventory work is relevant to the requirement relating to the provision of a substantiated proposal concerning the radiological capacity of the site. We remain concerned at the limited reporting and appraisal of inventory uncertainty. The latter aspect will require further consideration in relation to the definition of a radiological capacity for the site, which is discussed in greater detail in other parts of our review (Environment Agency, 2009a,d).

3.1.2 The work on inventory has provided information relating to the location and nature of specific uranium-bearing wastes that have been disposed to the trenches. This work, coupled with a revised conceptual model for uranium release, has been used to argue that the risks via the groundwater pathway which arise from such disposals will be considerably lower than those projected in the 2002 PCSC. We have raised some concerns about how this conceptual model has been underpinned and parameterised in the performance assessment; however, we do conclude that it improves the knowledge and understanding about the site. Overall, the improved definition of the location of specific waste streams will provide a useful input to appraisals of the necessity and practicability of potential interventions for trench disposals. More generally, the updated inventory will help to develop arguments to support proposals for the radiological capacity of the site.

3.2 Work on demonstrating best practice

3.2.1 Volume 3 summarises work on the assessment of site engineering and engineering performance. This is directly relevant to demonstrating how best practice will be used to ensure that post-closure risks are minimised, in so far as is reasonably practicable. Volume 3 and its supporting documents have described a single option – a revision of the engineering design for the site at closure initially proposed in the 2002 PCSC. We recognise that the engineering design remains to be optimised and specified in detail. We do conclude, however, that the key features of the design, as described to date, provide a sensible basis on which to proceed at this stage.

3.2.2 The work presented to us has argued that the combined functionality of the cap and a vertical drain (or drains) will prevent flooding of the facility, and thereby avoid any associated impacts from a "bathtubbing" scenario. Arguments that the vertical drain (or drains) will have "*sufficient capacity at all times*" will be contingent on their detailed design and performance, which cannot be appraised on the basis of the work presented to date. We consider that further work is necessary to demonstrate that these assumptions are valid and that such engineering performance is achievable in practice.

3.2.3 Current disposals – and those envisaged in any future disposal vaults – involve cement-based wasteforms within stacked, mild steel containers surrounded by an aggregate infill that permits water to flow preferentially around, rather than through, the waste. The use of cementitious wasteforms is recognised as good practice internationally. The potential benefits of an aggregate infill to reduce groundwater flow through the waste are also recognised.

3.2.4 Further work on the optimisation of wasteforms and containers may be appropriate as the LLWR programme proceeds, particularly if there is a move to increase the levels of waste incorporation and packing efficiencies. We also recommend a watching brief on superplasticiser technology, as we are aware of alternative materials that appear to offer advantages relative to Sikament 10.

4 Recommendations in relation to the environmental safety case

4.0.1 We have identified a number of recommendations that relate to the forthcoming update to the ESC. The following paragraphs provide a summary of the recommendations. The order of the recommendations does not imply any priority – the category to which each recommendation is allocated provides an indication of priority and of the level of response we expect.

4.0.2 In our view a major limitation of the work presented to date (Environment Agency, 2008) is its lack of a systematic treatment of uncertainty. This concern extends to the reporting and treatment of inventory uncertainty. A systematic treatment of inventory uncertainty should (**Category A recommendation** – see para. 1.5.4) be one component of the updated ESC, including an analysis of the implications of such uncertainties on projected risks and impacts.

4.0.3 Further work on inventory has identified certain waste streams that may arise for disposal at the LLWR in the future as major contributors to the inventory of particular radionuclides that are key risk determinants in the performance assessments to date. We recommend (**Category B recommendation**) that LLW Repository Ltd consider developing a process for assessing significant waste streams and their associated impacts through the site performance assessment. This approach would identify components in the projected inventory that are likely to present specific challenges. This assessment could be particularly important if proposals are to be made for any revisions to the site's waste acceptance criteria and/or the nature of the wastes and conditioned waste forms to be disposed at the site.

4.0.4 We are aware of initiatives that are looking to optimise the use of the repository volume. These approaches might include alternative container designs, possible waste pre-treatments and methods for maximising waste incorporation and packing efficiencies. Any such developments may change the form of the conditioned waste for disposal, the concentration of radionuclides, the ratio of waste to cement and the way in which the vault capacity is used. Any such developments might alter the site safety case (e.g. doses arising from intrusion will essentially scale with the concentration of the dose-determining radionuclides, arguments regarding the persistence of hyperalkalinity in the vaults may be further challenged if the waste-to-cement ration is decreased). Whilst recognising that this is work in progress and at a conceptual stage, we recommend (**Category A recommendation**) that such possibilities are analysed in relation to both site optimisation and in the development of the ESC.

4.0.5 We note that the engineering performance assessment, as presented in Volume 3, assumes that the performance of both the cap and the vertical drain(s) are sufficient to prevent "bathtubbing". Vertical drains are described as "*optional and of different design (location, type and plan area) in the Single Option*" although they are also assumed to provide "*sufficient capacity at all times*" as a sink for any flows arising from controlled overtopping (Gate 5). We recognise that site engineering is a matter for optimisation, but it is important that any assumptions about performance that are used in support of the full ESC are based on realistic and achievable performance. We expect (**Category D recommendation**) an appraisal of any impacts that might arise should future assessments of the site's engineering performance suggest that "bathtubbing" might occur. Where significant uncertainty in the likelihood of bathtubbing remains, it would be prudent to assess any related impacts should such a scenario arise.

4.0.6 A number of inputs presented in Volume 3 to the performance update are based extensively on the site understanding described previously in the 2002 PCSC. This includes the detailed description of the evolution of the near field which is projected using the DRINK model with parameters based on the inventory data and projected near field flow from the 2002 PCSC. Information from the 2002 DRINK model has been used directly in the performance update described in Volume 5. Specific examples include the "pseudo-solubility" values for C-14 and the projected timescales to site reoxidation. We recommend (**Category B recommendation**) that the validity of the 2002 DRINK model output is reappraised in the light of the revised inventory (radiological and non-radiological) and the changes in the conceptual understanding of site performance. If it is to be used further, and where necessary, the model should be reconfigured and parameterised to reflect current understanding. We emphasise that any future reliance on output from the 2002 DRINK model would mean that many of the issues relating to the use of DRINK that were identified by the Near Field Review Group (Galson Sciences Ltd, 2002) would remain valid.

4.0.7 A simplified FEP analysis is proposed for future assessments (relative to the 2002 case) in Volume 3. We do not disagree in principle with a simplified approach. We recommend, however (**Category B recommendation**), that any FEP analysis is suitably comprehensive so that it can support the definition of conceptual models and provide a systematic framework against which modelling uncertainties can be identified and assessed.

4.0.8 If the model for uranium residue leaching is to be developed further for deployment in the full ESC, we recommend (**Category B recommendation**) that further information is provided to justify the model and its parameters. Specific issues include:

(a) the assumption of congruent release of uranium during leaching;
(b) the sensitivity to variations in uranium content;
(c) the intrinsic dissolution rate of the fluoride matrix.

These aspects will need to be supported by suitable lines of evidence, which might include experimental data, waste characterisation, site monitoring data and/or logical arguments, as appropriate. The sensitivity of the model's output to remaining uncertainties should also be presented.

4.0.9 We recommend (**Category B recommendation**) that further justification is provided for the argument that the vault system will remain extensively hyperalkaline over the anticipated lifetime of the facility, and hence that representation of the vaults as a cementitious environment in the long term is a valid assumption. There should also be an appraisal of any related implications if the ratio of cement to waste is reduced in the future. Any remaining uncertainty related to the persistence and extent of hyperalkaline, cementitious conditions should be evaluated through a suitable sensitivity analysis.

4.0.10 It is our understanding that near field solubility and sorption parameters used in the recent performance update are based extensively on those used in the 2002 PCSC case, and as summarised in Volume 3. For example, "*In the current assessment, it is assumed that sorption can be treated as instantaneous and reversible, and is parameterised according to Kd values appropriate to soils in the Trenches, and soils and grout in the Vaults. Solubility limits are only relevant to a few radionuclides. Based on results from the 2002 PCSC (Subsection 6.5.1 of BNFL, 2002c), only thorium, uranium and carbon have been treated as solubility limited.*" (Volume 5, p. 32).

4.0.11 The representation of solubility in the 2002 PCSC was based extensively on thermodynamic considerations against selected proxy mineral phases containing specific elements. For example, in the case of the uranium radionuclides, the mineral phases were $CaUO_4$ in the vaults and UO_2 (am) in the trenches. Sensitivity studies looked at the impact of varying the solubility of such phases on projected risk. Likewise, sorption was represented in terms of K_d values for sorption onto particular substrates under specific conditions and variations in these values were considered in sensitivity analyses. The Near Field Review Group (Galson Sciences Ltd, 2002) identified numerous issues with this approach.

4.0.12 We noted and explained in paras 2.7.4–2.7.7 of this review that other programmes have elicited solubility and sorption ranges, based on experimental evidence, modelling studies, natural analogues and expert judgement. Such studies have defined probability density functions to describe the possible variations in solubility and sorption, which are then used in performance assessments.

4.0.13 We recommend (**Category B recommendation**) that the representation of solubility and sorption for the fully updated ESC due in 2011 makes it possible to conduct a comprehensive, suitably scoped and justified uncertainty analysis, supported by probabilistic calculations, where appropriate. Any future simplified representation of the near field should facilitate such an approach, which could prove useful in meeting Requirements 4 and 7 of the updated GRA (Environment Agency *et al.*, 2008). If correctly implemented, such an approach should enable a useful sensitivity analysis of possible variations in radionuclide mobility from the near field to the groundwater pathway. Such analyses could help to determine the scope of potential effects of colloids and superplasticisers (if their effects cannot be comprehensively characterised), the effects of organic species and how the evolution of conditions at the site may have impacts via the groundwater pathway.

4.0.14 Volume 3 suggests that the "best estimate" projection of the trench near field environment is that of an unsaturated system. If so, it may be appropriate to revise the modelling approach so it better reflects the expected conditions, or at least to explore and determine the scope of any related conservatisms. We recommend (**Category D recommendation**) that the ESC explores and scopes any of the related conservatisms associated with the representation of an unsaturated trench system by a saturated system model. This may not require much further work as we are aware, for example, that the output of experimental lysimeter studies has been used in the DRINK model to represent release from the unsaturated trench environment to the underlying saturated zone (BNFL, 1997).

4.0.15 We recognise that the facility is likely to be eroded within a few thousand years and that direct exposure pathways associated with exposed waste are likely to dominate the impacts during erosion of the facility. Nevertheless, we expect (**Category D recommendation**) the ESC to consider the effects of erosion on the groundwater pathway, including any effects of possible reoxidation of the near field as a result of erosion.

List of abbreviations

ALARA	As low as reasonably achievable
BNFL	British Nuclear Fuels plc
BNGSL	British Nuclear Group Sellafield Limited
CSH	Calcium silicate hydrate
Defra	Department for Environment, Food and Rural Affairs
DRINK	DRIgg Near Field Kinetic code
ESC	Environmental safety case
FEP	Feature, event or process
GPA	Generic Performance Assessment
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
PCSC	Post-closure safety case
PEG	Potentially exposed group
PGRC	Phased Geological Repository Concept
R&D	Research and development
RSA 93	Radioactive Substances Act 1993 (as amended)
RWMD	Radioactive Waste Management Directorate (of NDA)
SLC	Site licence company
UKAEA	United Kingdom Atomic Energy Authority
UKNWM	United Kingdom Nuclear Waste Management Ltd

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