# Independent Peer Review of LLWR Response to Environment Agency Schedule 9 Requirement 2

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## Report History

This document has been prepared by TerraSalus Limited for LLW Repository Limited. The document is based on review work conducted by an expert panel comprising staff from TerraSalus Limited, EnviroCentre Limited, Halcrow Group Limited, Intellisci Limited, Serco Limited, and Westlakes Scientific Consulting.

Draft 1 was prepared by D.G. Bennett (TerraSalus Limited) based on discussions at the meeting of the Peer Review Panel on 2 July 2008, and the record of peer review comments and responses. Draft 2 incorporates revisions made in response to comments and contributions received from all of the other members of the peer review panel.

Draft 2 was provided to LLWR Limited for information and to provide an opportunity for any points of factual inaccuracy regarding LLWR information to be identified.

Version 1 (dated 2 September 2008) incorporates minor changes which have been made in light of comments from LLWR Limited on matters of factual accuracy and presentation. Version 1 is not materially different from Draft 2 and accurately represents the view of the peer review panel.



| **Independent Peer Review of LLWR Response to Environment Agency Schedule 9 Requirement 2** | | | | |
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## Executive Summary

E1. The Low-Level Waste Repository (LLWR) has been the principal facility in the UK for the disposal of Low-Level Radioactive Waste (LLW) since 1959. The site is owned by the Nuclear Decommissioning Authority (NDA) and is operated on behalf of the NDA by a Site Licence Company (SLC).

E2. Disposals at the LLWR are authorised by the Environment Agency (EA) under the Radioactive Substances Act 1993. Schedule 9 Requirement 2 of the LLWR Authorisation requires that *'The operator shall 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. costal erosion and glaciation) and future human action'*.

E3. This report records the comments of an independent peer review panel that was asked by the SLC to review the submission made in response to Schedule 9 Requirement 2.

E4. The peer review panel considers that the submission made in response to Requirement 2 and provided to the EA on 1 May 2008 had improved considerably in the time since the peer review panel reviewed the work in early April 2008. Many of the changes and developments have resolved peer review comments, and the SLC's project team has acknowledged the benefit provided by the peer review. Inevitably and appropriately some peer review comments and issues remain to be dealt with. The SLC is planning further work to address the remaining issues in the lead up to the next safety case.

E5. The safety assessment work described within the submission has led to some important developments in terms of understanding how the site may evolve, and the structure of the next safety case, but the peer review panel considers that for several reasons (uncertainty in which regulatory criteria apply, limited treatment of uncertainty in the assessment calculations, limited traceability of assessment data, etc) it would be premature to draw any firm conclusions from comparisons of the current assessment results (doses and conditional risks) with quantitative regulatory criteria. The SLC acknowledges that the work does not represent a full safety assessment and that it includes only a limited treatment of uncertainties.

E6. The submission does not demonstrate that risks are as low as reasonably achievable (ALARA), but it does indicate a firm commitment to the next safety case and to making a robust ALARA demonstration. This seems appropriate given the various uncertainties that exist.

E7. The principal 'threats' to the safety performance of the LLWR have been identified as (i) facility destruction by coastal erosion, and (ii) inadvertent

human intrusion, particularly into localised volumes of waste in the trenches that possess relatively higher concentrations of long-lived radionuclides.

E8. The submission indicates that probability of facility destruction by coastal erosion is now believed to be essentially one. Studies conducted for the SLC suggest that (i) the LLWR will be eroded and destroyed by the sea in a fairly well-defined period, beginning relatively soon (750 to 2,500 years) after repository closure, and (ii) the sea may flood and inundate the eastern parts of the LLWR site, but not the capped area, even earlier than this (100-1,000 years) due to a combination of increasing sea level and high tides. Even if sea-level rise is disregarded, coastal erosion will affect the LLWR in several thousand years. The peer review panel believes that the high probability and short timescales for inundation and erosion of the facility raise questions regarding the suitability of the site for near-surface radioactive waste disposal, particularly for wastes containing long-lived radionuclides.

E9. The SLC has commissioned several recent studies to refine the waste inventory. These have resulted in improved inventory estimates at a much greater level of detail than was available for the 2002 safety cases. We agree with the SLC that further analysis is required to determine where the balance lies between the pros and cons of retrieving certain localised volumes of waste in the trenches that possess relatively higher concentrations of long-lived radionuclides. In order that risks can be shown to be ALARA, we suggest that the issue of localised waste retrieval needs to be assessed in more detail, with much greater transparency, and with specific reference to particular localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides.

E10. With regard to the strategy being proposed for the LLWR, the peer review panel agrees with the SLC that:

- A final site cap will be essential.
- A period of active institutional control after waste disposals cease will be essential.
- Coastal defences cannot be relied on to protect the LLWR from erosion in the long-term (i.e., for timescales relevant to long-lived radionuclides).
- The pros and cons of retrieval from the trenches of localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides need further analysis.

E11. In April 2008, the peer review panel suggested that the SLC should not be definite on the need for the vertical drains, the vault base liner, or the cut-off walls – this is still our view. These features are still part of the proposed strategy, but the submission and the SLC recognise the need for further optimisation of the design, and we support this. Overall, therefore, the peer review panel is now more comfortable and able to support the main conclusions on strategy proposed in the submission.

E12. Peer review is an ongoing process and will need to continue throughout the programme leading to the next safety case.

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# Independent Peer Review of: LLWR Response to Environment Agency Schedule 9 Requirement 2

## 1 Introduction

1. The Low-Level Waste Repository (LLWR) has been the principal facility in the UK for the disposal of Low-Level Radioactive Waste (LLW) since 1959. The site is owned by the Nuclear Decommissioning Authority (NDA) and is operated on behalf of the NDA by a Site Licence Company (SLC). United Kingdom Nuclear Waste Management (UKNWM) Ltd. holds a contract from the NDA for the management and operation of the LLWR, and shares in the SLC were transferred to UKNWM Ltd. on 1st April 2008.

2. Disposals at the LLWR are authorised by the Environment Agency (EA) under the Radioactive Substances Act 1993. The LLWR receives wastes from a range of consignors including nuclear power stations, fuel cycle facilities, defence establishments, general industry, isotope manufacturing sites, hospitals, universities and from the clean-up of historically contaminated sites.

3. In 2002, the previous operator of the site, British Nuclear Fuels plc (BNFL), provided the EA with environmental (operational and post-closure) safety cases for the facility (BNFL, 2002a; 2002b). These safety cases were reviewed by the EA (Environment Agency 2005a) and, following a period of consultation, a new authorisation was granted (Environment Agency, 2006a). The authorisation includes several schedules, of which Schedule 9 is a list of improvements and additional information that the operator must supply.

4. Schedule 9 includes Requirement 2, which amongst other things (see below) requires, by May 2008, a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. Requirement 2 is one of several that may be seen as important precursors to Requirement 6, which requires an update the environmental safety cases by May 2011.

5. The SLC has initiated a programme of work – the LLWR Lifetime Programme – to address the requirements of Schedule 9, and is subjecting the work of the programme to independent peer review.

### 1.1 Peer Review

6. Peer review is a formally documented examination of a technical programme or specific aspect of work by a suitably qualified expert or group of experts who have not been directly involved in the programme or aspect of work. The EA has indicated that it expects peer review to be used as one means of building confidence in the environmental safety

cases, and has stated that such peer reviews should be fully documented and provided to the EA (Environment Agency 2005a; Environment Agency *et al*. 1997; 2008).

7. In its review of the 2002 safety cases (Environment Agency, 2005a), the EA acknowledged that the previous operator, BNFL, had commissioned an independent peer review (Hill and Irvine 2002), but considered that this had been done at too a late stage in the development of the safety cases and that, as a result, not all of the peer review comments had been addressed adequately when the safety cases were submitted. The EA, therefore, emphasised in its review the need for peer review to begin at an early stage in the project and to be an active and continuous part of work leading to revision of the safety case.

8. Fully recognising the need for peer review, the SLC has established a new independent peer review panel, which is made up of six highly-qualified senior specialists (Appendix 1). The peer review panel members were selected by the SLC during early 2007, and collectively have considerable expertise and experience in radioactive and conventional waste management, and in environmental management more generally. The peer reviewers also have specific and detailed knowledge of the LLWR site and facility. Importantly, the peer review panel members are completely independent of the team working on behalf of the SLC to develop responses to the Schedule 9 requirements, including the safety cases.

9. The remit of the peer review panel extends across the whole of the Lifetime Programme and the Modular Vaults Project (MVP), which includes work on the design of the LLWR. The overall objectives of the peer review panel are to:

- Provide timely independent review of key technical approaches, arguments, designs, assessments and safety cases being developed by the SLC's project team.

- Work in such a way that it can be demonstrated to relevant stakeholders that a rigorous and effective process of review and scrutiny is operating.

10. The peer review work is focusing on issues that are the most important to the risks associated with the LLWR, and is assessing and commenting on whether the work of the Lifetime Programme and Modular Vaults Project are consistent with policy, regulation and best practice, so as to identify areas where improvements may be made.

## 1.2 Schedule 9 Requirement 2 and Peer Review Objectives

11. Schedule 9 Requirement 2 states:

- '*The operator shall 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. costal erosion and glaciation) and future human action.*'

12. The SLC is required to respond to this requirement on 1 May 2008 and '*at such intervals thereafter as the Agency specifies in writing'*.

13. The most obvious objective of peer review for the S9R2 submission would be to consider whether the submission meets the Requirement as stated above. However, the wording of the Requirement is open to some degree of interpretation, and the peer review panel understands that the EA's expectations of the submission have been the subject of dialogue between the SLC and the EA, and have broadened since the date of the Authorisation. The peer review panel has, therefore, reviewed the submission against its own objectives as stated in the submission.

14. These wider objectives have included addressing two additional points given in the EA's Decision Document (see page 54 of EA 2006b), which suggest that the submission should provide the EA with:

- '*…adequate information to allow the radiological capacity of the site to be determined…*' , and
- '*…the outcome of a wide-ranging risk management study… …that demonstrates that future impacts will be As Low As Reasonably Achievable…*'

15. The peer review panel notes that these points would logically be based on a full update to the 2002 safety cases, including a comprehensive safety assessment (e.g., as will be developed to meet Schedule 9 Requirement 6).

## 1.3 This Report

16. This report records the comments of an independent peer review panel that was asked by the SLC to review the submission made in response to Schedule 9 Requirement 2. The peer review panel has developed this report based primarily on the information provided in the five volumes that comprise the submission (Table 1), but the panel has also reviewed some of the documents that support the five volumes. The panel has also considered information provided by the SLC's project team in response to initial peer review comments, and during peer review meetings.

**Table 1 The main volumes comprising the submission**

| Reference | Title |
|---|---|
| LLWR (2008a) | Managing Existing Liabilities and Future Disposals at the LLWR. Report No. 100001 LLWR LTP Volume 1, Issue 01. |
| LLWR (2008b) | Assessment of Options for Reducing Future Impacts from the LLWR. Report No. 100002 LLWR LTP Volume 2, Issue 01. |
| LLWR (2008c) | Inventory and Near field. Report No. 100003 LLWR LTP Volume 3, Issue 01. |
| LLWR (2008d) | Site Understanding. Report No. 100004 LLWR LTP Volume 4, Issue 01. |
| LLWR (2008e) | Performance Update for the LLWR. Report No. 100005 LLWR LTP Volume 5, Issue 01. |

17. In keeping with best practice in independent reviews (e.g., NEA 2005a), neither the SLC nor its contractors have commented on the technical content of this report – the SLC has, however, had the opportunity to check for factual accuracy. The peer review panel has made its best effort to ensure that all information is accurate.

18. The report is structured as follows:

- Section 2 gives a brief description of the peer review approach and processes that are being followed.
- Section 3 summarises the comments of the peer review panel on aspects of the Requirement 2 submission that relate to disposal facility performance, i.e. the safety assessment. This section is structured broadly following the IAEA ISAM methodology (IAEA 2004).
- Section 4 summarises the comments of the peer review panel on the SLC's review of options and proposed strategy for reducing the peak risks from the LLWR. This section, thus, addresses some of the safety case arguments that go beyond the quantitative safety assessment issues discussed in Section 3.
- Section 5 presents key conclusions from the peer review.
- Section 6 provides a list of references.
- Appendix 1 comprises brief CVs for the peer review panel.

# 2 Peer Review Approach and Process

## 2.1 Approach

19. At the beginning of the peer review process it was agreed that:

- The peer review would be objective and undertaken to the highest standards of probity, based on the principles of good science and engineering. The approach to the review would be consistent with relevant international guidance on reviews of radioactive waste disposal programmes (NEA 2005a, b; IAEA 2007).

- The review panel would be strictly independent of, and separate from, those involved in the work of the Lifetime Programme and/or the MVP that are developing the safety cases for the LLWR.

- Formal methods would be used to ensure that a clear and traceable record is made of review comments and responses received.

- The review would be conducted so that, as far as possible, the output from the review panel would represent a consensus view rather than a set of individual opinions. If there were significant un-resolvable differences of view amongst the review panel, then the different views would be recorded[1].

- The peer review would be conducted in a practical way that fits in with the schedules of the Lifetime Programme and the MVP, and enables them to respond and react appropriately to peer review comments. Peer review activities would, thus, comprise two principal activities: document reviews and peer review meetings.

- Key documents from the Lifetime Programme and MVP would be identified for review. The peer review panel would not seek to review all of the many deliverables that are being produced under the Lifetime Programme and MVP, but would, instead, identify key areas for review and select individual documents or related sets of documents for review. In addition, it was envisaged that the SLC would request peer reviews of particular documents.

- Documents would be reviewed by at least two members of the peer review panel. Results from document reviews would be recorded in Interim Review Papers. These Interim Review Papers would be provided to the SLC's project team as they were produced, thus enabling early sight of the review comments and a chance to react as appropriate. The Interim Review Papers would form the basis for the development of formal Review Reports (such as this report).

[1] In practice this has not been necessary.

- Formal Review Reports would be produced at key times in the schedule and would be provided to the regulators, together with the SLC's responses to the peer review findings.

## 2.2 Process

20. The peer review panel met for the first time in September 2007 to discuss its organisation and to receive presentations from the SLC's project team on on-going work, which included the development of the submission made in response to Requirement 2. During the latter part of 2007 and early 2008 members of the peer review panel:

- Attended two meetings with stakeholders to assess management options for the trenches (Bennett and Jones 2007; 2008)

- Briefly reviewed several draft contractor documents prior to their discussion at the Lifetime Programme Technical Committee.

- Visited the LLWR site and met for a second time with the SLC's project team (Bennett 2008).

21. At the latter meeting it was agreed that the peer review panel would review drafts of the five volumes comprising the Requirement 2 submission and that the review panel would record its peer review comments on formal comment and response forms.

22. In completing its submission made in response to Requirement 2, the SLC's project team took account of the peer review panel's comments, and recorded on the comment and response forms whether (and, if so, how) the peer review comments had been addressed. The peer review panel then reviewed the responses to the comments and the final versions of the volumes comprising the Requirement 2 submission.

23. A series of peer review comments were developed on key aspects of the Requirement 2 submission and these are recorded in the following sections of this report. The main peer review comments were presented to the SLC's project team at a meeting held on 2 July 2008 for their information and with the aim of identifying any factual inaccuracies.

# 3 Peer Review of the 2008 Performance Update

## 3.1 Assessment Context

### 3.1.1 Assessment Purpose and Philosophy

24. Volume 5 of the submission (LLWR 2008e) addresses the post-closure radiological performance of the LLWR. LLWR (2008e) recognises clearly that the volume '*does not present a comprehensive post-closure performance assessment*', and that '*The uncertainties related to models and data are not fully explored as will be required within the 2011 PCSC; hence the results are to some extent interim*'. The peer review panel acknowledges these caveats and notes that they must be borne in mind when considering the implications of the work.

25. In many places LLWR (2008e) describes particular assumptions, modelling approaches or parameter values as '*cautious'*, meaning that they lead, in the SLC's view, to an overestimate of dose or risk. The peer review panel considers that there is a clear logic to most of the SLC's statements of this type (e.g., regarding the source term). However, the peer review panel considers that there are also instances where the treatment or omission from the assessment calculations of particular FEPs (Features, Events, Processes) means that it is not possible to be confident that the assessment is cautious in an overall sense. Such instances relate, for example, to the possible occurrence of further exposure pathways associated with coastal erosion, to assumptions made in the engineering performance assessment, and to assumptions regarding the effectiveness of passive institutional controls. Our comments on these examples are documented more fully in the following sections. The review panel considers that a more thorough treatment of uncertainty will be necessary for the next safety case.

### 3.1.2 Regulatory Criteria and Assessment Endpoints

26. LLWR (2008e) presents arguments as to what are the appropriate reference levels to use when considering assessed doses and/or risks associated with the LLWR trenches and vaults under different circumstances. A summary of the SLC's position is given in Table 2.1 of LLWR (2008e).

27. First, LLWR (2008e) proposes that a dose rate of 10 mSv/year should be used as a reference level when considering the impacts from the trenches, however they arise (whether as a result of natural processes or as a result of inadvertent human intrusion). The peer review panel notes that this proposal is not consistent with the approach taken previously by the EA, which has argued that, at least for releases as a result of natural processes, the risks associated with the trenches should be considered together with those from the rest of the site and should be compared to the GRA target

for mean annual individual risk (Environment Agency *et al.* 1997; Environment Agency 2005a). The peer review panel understands that since 2005, there has been dialogue between the SLC and the EA on this issue, and considers that the EA needs to clarify in a publically available document exactly which regulatory criteria will be used when considering the LLWR trenches.

28. Second, LLWR (2008e) proposes that a reference level dose rate of 10 mSv/year should be used when considering impacts that may arise as a result of inadvertent human intrusion (whether into the trenches or vaults). The SLC's rationale for this is that this approach has been proposed in ICRP Publication 81 (ICRP 2000). The peer review panel notes that the approach of using a dose-based reference level for human intrusion scenarios (as opposed to a risk-based standard or level) has become more widely accepted since 2000. However, the peer review panel notes that a range of views exists as to the dose rate at which the reference level should be set, for example:

- In its more recent publication (ICRP 2008) the ICRP has suggested that a figure of less than 1 mSv/year should be considered for public exposures in planned situations (planned situations include radioactive waste disposal), and that a band from 1 to 20 mSv/year should be considered for occupational exposures in planned situations, and for public exposure to radon in dwellings.

- EA (2008) suggests that the assessed effective dose rate to any person during and after the assumed intrusion should be consistent with a dose guidance level in the range of around 3 mSv/year to around 30 mSv/year, with values towards the lower end of this range applicable to assessed exposures continuing over a period of years (chronic exposures).

- HPA (2008) proposes that exposures resulting from inadvertent human intrusion and lasting more than five years should be considered using an annual dose guidance level of 3 mSv/year.

29. The peer review panel considers that because of the uncertainty associated with the regulatory criteria to be applied to the LLWR, particularly in respect of the trenches and inadvertent human intrusion, the SLC may have to revise its position on the appropriate reference levels.

30. With regard to assessment endpoints, LLWR (2008e) presents selected results from calculations of dose and conditional risk to members of a range of potentially exposed groups. The peer review panel would have liked to see a more comprehensive presentation of the assessment calculations and results, including results from all of the calculation cases, results for all of the identified potentially exposed groups (PEGs), and more results for intermediate performance measures. The peer review panel also notes that because of the limited treatment of uncertainty in the

assessment calculations, *risk* has not been evaluated in any sense that could properly be compared on a like-for-like basis with the mean annual individual risk target in the GRA (Environment Agency *et al*. 1997).

### 3.1.3 Assessment Timeframe

31. A significant change to the safety assessment for the LLWR since the 2002 PCSC (BNFL 2002b) has been to consider a much shorter assessment timescale (~5,000 years instead of ~60,000 years). In the 2002 PCSC, facility destruction by coastal erosion was assessed as being 'likely' (BNFL 2002b). This was interpreted by the EA (2005a) as meaning that the probability of facility destruction by coastal erosion was greater than 0.5. The current assessment (LLWR 2002e) includes facility destruction by coastal erosion within the expected evolution scenario for the site, reflecting the view of Thorne (2007) and Thorne and Kane (2007) that the LLWR will be eroded and completely destroyed by the sea in a fairly well-defined timescale of less than 5,000 years, relatively soon after repository closure. That is, the probability of facility destruction by coastal erosion is now believed to be essentially 1.0.

32. This change to the assessment timeframe is one factor that contributes to the assessed *peak* doses and risks being lower than they were in the 2002 PCSC. This is because there is less time for in-growth of the daughters of certain long-lived radionuclides that contributed significantly to the exposures evaluated in the 2002 assessment. Other factors contributing to the lessening of assessed peak doses and risks include the reduced importance of the groundwater pathway (see paragraph 62), and the use of a new model for assessing doses resulting from exposure to radon and thoron (see Section 3.4.5).

33. The peer review panel's comments on the underlying rationale for the shortened assessment timeframe are summarised in Section 3.2.4. Previously, review comments have suggested a need for the use of simple scoping calculations to address impacts after facility destruction (e.g., after glaciation of the site - see EA 2005a and references therein). In the present circumstances, where site destruction by erosion is now believed to be essentially certain and the impacts of waste dispersal on the shore and into the sea have been assessed as part of the mainline assessment, *there seems to be little need for additional consideration of longer timescales* (as long as the mainline assessment calculations properly address all of the relevant exposure pathways and PEGs during and after facility destruction e.g. in the lagoon system – see Sections 3.3.2 and 3.4.4).

## 3.2 Disposal System Description and Understanding

### 3.2.1 Waste Inventory

34. The SLC has commissioned several recent studies to refine the waste inventory (e.g., Lennon *et al*. 2008; Wareing *et al*. 2008). These studies have resulted in improved inventory estimates at a much greater level of detail than was available for the 2002 safety cases. The recent studies have made a significant and positive contribution to risk management for the site. The review panel has found that it is necessary to examine the references that underpin the five volumes comprising the submission made in response to Requirement 2 in order to properly understand the results of the recent inventory work.

35. There is now a much better understanding of the spatial distribution of radionuclides in the trench wastes (see figures 1 and 2 of Lennon 2007). Lennon *et al*. (2008) shows that there are localised concentrations of Th-232 in Trenches 2 and 3. Greater than 26% of the Th-232 occurs in less than 1% of the trench bays. In addition, one of the spatial concentrations of Th-232 in Trench 2 coincides spatially with the most significant concentration of Ra-226. Such localised concentrations of radionuclides represent potential targets for intervention and should be assessed further as part of the work to determine whether localised waste retrieval or some other type of intervention is justified (see Section 4.2.1). Localised volumes of waste possessing relatively higher concentrations of radionuclides were described by the Environment Agency as '*hot spots'* (Environment Agency 2005a; 2006b).

36. While much useful work has been done on mapping the spatial distribution of radionuclides in the trenches, the peer review panel considers that further work remains to be done in the lead up to the next safety case in order to deal with some of the remaining uncertainties associated with the trench waste inventory (e.g., those raised by local stakeholders at the BPEO workshops related to unrecorded disposals - Collier, 2008a).

37. LLWR (2008c) indicates that compared to the inventory used in the 2002 PCSC, the uranium content of the trenches is now believed to be lower by a factor of approximately two. Conversely, if as is assumed for the assessment calculations reported in LLWR (2008e), all of the waste streams in the 2004 National Inventory for which the future disposal route is declared as the LLWR were actually to be disposed of to the LLWR, then there would be some significant increases (as compared to the 2002 PCSC inventory) in the amounts of long-lived radionuclides going into the vaults. For example, in the 2002 PCSC the Np-237 content of the future vaults was estimated to be 0.01 TBq, whereas the current estimate is 3.21 TBq - an increase of approximately 300 fold. This would mean that the future vaults would contain ~100 times as much Np-237 as the rest of

the facility (trenches plus Vault 8). LLWR (2008c) indicates that the largest increases in the inventory of long-lived nuclides (e.g., U, Np) are associated with just a few waste streams, such as waste stream 2E101 (Springfields decommissioning LLW).

38. The current estimates of the inventory disposed of to date in the trenches and in Vault 8 rely largely on declarations made at the time of disposal. For radionuclides of importance in the performance assessment, it would be prudent to review knowledge of the waste producing processes, to see whether significant additional undeclared amounts of the key radionuclides could be present within major waste streams. For example, could Np-237 have been present in significant amounts in past disposals of waste from Springfields?

39. At the time of the last authorisation review, a key argument used in favour of allowing waste disposal to continue at the LLWR, was that future disposals would not appreciably increase peak annual risks and that restrictions on future disposals would have limited potential for reducing long-term environmental impacts (see Environment Agency 2005b, para. 6.48). The review panel notes that the inventory estimates used in the Requirement 2 submission mean that this argument would no longer hold.

40. The submission made in response to Requirement 2 does not describe possible alternative assumptions about which wastes might come to the LLWR in future, but instead defers this topic to a separate UK LLW strategy development process. Given this, we consider that the impacts for the LLWR of accepting different type of waste might be explored in the next safety case. The EA has asked for consideration of short-lived wastes (EA 2005a) and, in detail, various options might be possible. The peer review panel doubts that the LLWR should receive large amounts of unprocessed soils and rubble from other decommissioning sites as is suggested might be the case by Figure 4.3 of LLWR (2008c).

### 3.2.2 Engineered Facility

41. The remit of the peer review panel includes the MVP and the design of the LLWR but, to-date, the panel has not had an opportunity to review the design in any great detail.

42. The peer review panel acknowledges that facility design is not a primary focus of the submission made in response to Requirement 2, but considers that the design could usefully have been described in more detail and should have been presented more consistently across the five volumes comprising the submission.

43. The submission does not describe the rationale for the design or its justification. The peer review panel notes that, consequently, it is difficult to assess design option choices.

44. The peer review panel agrees that construction of a final cap is best practice in near-surface radioactive waste disposal and will be essential (to limit infiltration and reduce the potential consequences of inadvertent human intrusion), but considers that further optimisation of the cap design may be needed. For example, we are yet to be convinced that the proposed profile for the cap incorporating a central valley (see Figure 2.3 of LLWR 2008c) is optimal, and we have concerns that it may be relatively more susceptible to cracking and failure due to differential settlement of the underlying waste than possible alternative designs.

45. The peer review panel suggests that the SLC should consider a staged programme of cap construction because this would provide an opportunity to trial and improve the cap construction process, to monitor cap performance, and to gather data on which to base models of cap performance.

46. The peer review panel is not fully convinced by the justifications provided for the vertical drains, the vault base liner, or the cut-off walls. Collectively these features (together with the cap) are designed to prevent '*bath-tubbing*'[2] and terrestrial discharge. The peer review panel considers that the avoidance of bath-tubbing and terrestrial discharge should be a key design aim, but we are yet to be convinced that the proposed system will achieve this. For example, we are not convinced that with their current proposed design, the vertical drains would continue to operate for the required period and would not become clogged. The peer review panel considers that a simpler facility design with a permeable vault base might be better.

47. We acknowledge that the SLC is planning further optimisation work on the facility design and we support this. We would also encourage the SLC to review LLW disposal practices in other waste management programmes (e.g., within Europe), with the aim of identifying examples that support the disposal practices and engineering measures being proposed at the LLWR.

### 3.2.3 Geology and Hydrogeology

48. The geology and hydrogeology of the LLWR site and its immediate surroundings are lithologically and spatially complex, and there have been several attempts leading up to the 2002 PCSC and subsequently to develop models of the geological structure and of groundwater and surface water flows. Different modelling teams have had different views on how the system should be represented and modelled, and over the years, considerable resources have been put into the problem. LLWR (2008d) summarises the most recent work. However, some of the

[2] Bath-tubbing is when the facility fills with water and this becomes contaminated and discharges over the top of the facility walls into shallow groundwaters, the surrounding land or into streams etc.

supporting reports, e.g., Arthur *et al*. (2008), were not available to the peer review panel in time for this review.

49. With regard to geology, the peer review panel considers that the change from the event-stratigraphy-based geological model used in the 2002 PCSC to one based on lithological packages (LPs) gives the appearance of being a sensible development. However, the LP model fails to deliver on its promises to better inform the modelled domain in any quantifiable way. This may be related to the particular LP approach adopted being too simplified. In particular, the approach does not represent deterministic features of sedimentological heterogeneity (e.g., interconnected sandy lenses or channels such as those that may account for the groundwater tritium migration pattern). Consequently, there is some concern as to how much credence should be attached to the LP approach.

50. With regard to hydrogeology, the peer review panel considers that the adoption of the LP approach has not significantly improved the link between the geology and the hydrogeological interpretation and model. The credibility of the groundwater model, and its robustness, will need to be improved, for example, by showing how well the model represents the effects on groundwater movements of localised lithological heterogeneities, such as more permeable lenses and palaeochannels. Confidence that the groundwater model is fit for purpose also needs to be improved by taking a more rigorous approach to model calibration (e.g., through the use of accuracy criteria), by explaining the reasons for any failure to achieve satisfactory model calibration against observed data, and possibly by testing transport predictions against the results of monitoring for tritium and other radionuclides in groundwater[3].

51. The peer review panel agrees that the evidence from piezometry and from tritium migration studies indicates that the predominant pathway for leachate to enter groundwater is downwards to the deeper part of the groundwater system. The tritium releases also identify certain pathways into shallow groundwaters, which end up in various drains and streams (LLWR 2008d). We consider that the confidence in the groundwater model of these shallow pathways and of how they might evolve over time needs to be further enhanced.

52. One aspect of this will be improvements in the diagrammatic presentation of information. For example, the peer review panel would have liked to have seen:

- Better explanations of the particle tracking work (see figures 5.7-5.9 of LLWR 2008d), which relies on the interaction of near-field and far-field hydrogeology.

[3] It is recognised that a fully quantitative model confirmation is not likely to be possible because of uncertainties in the magnitude and spatial distribution of the source term.

- Additional results from the flow models (e.g., flow patterns, relative flows in drift and underlying sandstones) to complement the particle tracking results presented in LLWR (2008d).

53. Other aspects relating to hydrogeology and the understanding of the potential for radionuclide transport that may need to be improved for the next safety case include:

- Additional hydrogeological data between the site and the coast (it is understood that the SLC has this in its plans for future work).

- Confidence in the transport and retention modelling of the key radionuclides in both shallow and deeper groundwater pathways, using monitoring data for confirmatory testing as far as is possible.

54. Given the difficulties in modelling the hydrogeology of the site, the peer review panel considers that it will be important for the next safety case to include an adequate range of sensitivity studies that provide confidence that the risks associated with the groundwater pathway have at least been bounded.

55. We acknowledge that the submission made in response to Requirement 2 recognises that the hydrogeological models should be seen as '*work in progress*' and that the models will be further developed prior to the next safety case (LLWR 2008d). We consider that the aim of such development work should be models that are only as detailed as necessary, consistent with the reduced importance of the groundwater pathway in the safety assessment (see para 62).

### 3.2.4 Site Evolution

56. Over the next few thousand years, coastal erosion and climate will be the main drivers of environmental change at the LLWR (LLWR 2008e). The peer review panel considers that the SLC has undertaken a thorough examination of the various factors that may influence the climate (Thorne 2007; Thorne and Kane 2007). These references have suggested that BIOCLIM scenarios B3 and B4 (BIOCLIM 2004) can be used in the safety assessment to capture the likely range of effects on climate of fossil fuel utilisation. We note that other near-surface radioactive waste disposal programmes (e.g., Mallants *et al*. 2008) have also come to similar conclusions regarding the representation of climate in safety assessments, i.e., by using BIOCLIM scenarios B3 and B4.

57. These scenarios are expected to involve significant sea-level rise and to cause erosion of the coastline, which will reach the LLWR on a timescale of 750 to 2,500 years from now (Thorne 2007). Even if sea-level rise is disregarded, it is concluded that coastal erosion will affect the LLWR in several thousand years (Table 6.1, LLWR 2008e). Halcrow (2008) suggests that the sea may flood and inundate the eastern parts of the

LLWR site, but not the capped area, even earlier than this (100-1,000 years) due to a combination of increasing sea level and high tides. Whilst we have found no obvious flaws in the link between the climate scenarios and facility destruction by erosion, we suggest that the link might be subjected to further scrutiny.

58. The peer review panel believes that the high probability and short timescales for inundation and erosion of the facility raise questions regarding the suitability of the site for near-surface radioactive waste disposal, particularly those containing long-lived radionuclides. For example, IAEA Safety Requirement WS-R-1 on Near-Surface Disposal of Radioactive Waste states '*The frequency and intensity of processes affecting the stability of land forms such as flooding, erosion, landsliding or weathering shall be such that they would not significantly affect the ability of the disposal system to isolate the radioactive waste'* (IAEA 1994).

59. This site suitability issue is not directly addressed in the submission made in response to Requirement 2, but the peer review panel considers that the justification for continued disposals at the site (i.e., to the vaults), particularly of long-lived wastes, needs to be tackled head-on.

60. We understand that the SLC regards consideration of whether the LLWR facility should continue to receive waste for disposal, given the threat of coastal erosion, to be part of the on-going UK LLW management strategy development process. We note that the issue is also central to the safety case for the LLWR and that, logically, there should be a two way transfer of information between the LLWR safety case and the LLW management strategy.

## 3.3 Development and Justification of Scenarios

### 3.3.1 Scenarios

61. For the 2002 PCSC, BNFL undertook a formal scenario development process, including an extensive analysis of FEPs. BNFL (2002b) identified a Central Projection Scenario and scenarios involving future human actions. BNFL (2002b) distinguished three variants of the Central Projection Scenario according to whether they ended with destruction of the repository by coastal erosion, valley glaciation or regional glaciation.

- BNFL's coastal erosion variant was characterised by a period of intensifying enhanced global warming and progressive sea-level rise. This resulted in gross disruption of the repository by coastal erosion in the period 500-1,000 years after present.

- BNFL's valley glaciation variant was characterised by a period of mild global warming during which the repository could be disrupted by coastal erosion in the period 2,000-5,000 years after present.

This was followed by global cooling under hyper-oceanic conditions and repository disruption by valley glaciation in the period 20,000-40,000 years after present.

- BNFL's regional glaciation variant was characterised by a period of mild global warming during which the repository could be disrupted by coastal erosion in the period 2,000 and 5,000 years after present, followed by global cooling under relatively dry conditions. Gross disruption by regional glaciation was projected in the period 60,000-100,000 years after present, under conditions of greatly reduced sea level.

62. The more recent work discussed in Section 3.2.4 (Thorne 2007; Thorne and Kane 2007) has led logically to the elimination of the glaciation variants from the safety assessment, without the need for a new detailed scenario development process. The elimination of the glaciation variants has the effect of greatly reducing the importance of the groundwater pathway in the assessment because it was during the glaciation variants that there was the possibility of sea-level fall leading to exposures on emergent land to the south west of the facility. Overall, we consider that the changes since the 2002 PCSC are logical and help to increase focus on the central issue of coastal erosion. The estimated timing and duration of coastal erosion have been refined, but are not significantly different from those assumed in the 2002 PCSC coastal erosion variant.

63. Future human actions scenarios are discussed in Section 3.4.6. Comments on the inclusion or exclusion of certain potential exposure pathways in the safety assessment scenarios are provided in Section 3.4.

### 3.3.2 Potentially Exposed Groups

64. Potentially exposed groups have been identified in a separate supporting study (Thorne 2007). Thorne (2007) describes changes to the approach adopted in the 2002 PCSC, referring specifically to comments made by the EA on the treatment of PEGs in the 2002 assessment (Environment Agency 2005a).

65. The Thorne (2007) study appears to be quite comprehensive. The range of PEGs identified is adequate to cover the exposure scenarios that may arise from either natural evolution or inadvertent human intrusion scenarios, and the key parameter values that would be used to relate concentrations in environmental media to dose (occupancy times, inhalation and ingestion rates) are clearly described and appear reasonable.

66. However, it is not clear from Volume 5 of the Requirement 2 submission (LLWR 2008e), that the PEGs as defined by Thorne (2007) have been comprehensively considered in the assessment to date. For example:

- Thorne (2007) correctly identifies ‘users of the estuary and lagoon’ as a PEG, but it is not obvious from LLWR (2008e) that doses to this PEG have been assessed.

- Agricultural smallholders making use of the cap area are identified as a PEG in Thorne (2007). LLWR (2008e) indicates that the potential exposures of this PEG have been assessed for the cases of inadvertent human intrusion and following releases of radionuclides to the north-west gullies and ditches (LLWR 2008e, Table 4.3). The peer review panel, suggests, however, that this group might also be affected via other pathways, such as gas release through defects in the cap (in the absence of inadvertent human intrusion), or wind-blown material arising from the advancing front of coastal erosion.

- Thorne (2007) notes current evidence of utilisation by local farmers of beach material for construction of roads and walls. Again, it isn’t clear whether this potential pathway of exposure is considered in the coastal erosion scenarios described in LLWR (2008e).

67. In summary, the PEGs as currently defined form a reasonable basis for the assessment, but more consideration is needed to ensure that all processes that may contribute to their exposure and risk have been incorporated into the assessment.

## 3.4 Assessment Modelling

68. The peer review panel has not undertaken a comprehensive, detailed review of the assessment models used in developing the Requirement 2 submission for the following main reasons:

- Many of the conceptual models are the same as those used in the 2002 PCSC.

- The interim nature of the current assessment does not warrant such a detailed review at this stage.

- Documentation describing the models in detail has not always been available, and there has been limited time for peer review work.

69. In this section, therefore, we comment on selected parts of the assessment models and focus largely on key assumptions, particularly where new approaches have been adopted since the 2002 PCSC.

70. More detailed review of the assessment models, parameter values and supporting data, as well as of the accuracy and calibration of the supporting models, and the use of the assessment models for uncertainty and sensitivity analyses will need to be part of the programme leading to the next safety cases.

### 3.4.1 Engineering Performance

71. Section 6 of LLWR (2008c) summarises the approach taken in Paksy (2008) to considering and quantifying water flows through the engineered components of the disposal facility. Water flows through the facility and its engineered features have been estimated using parameter values either derived from an expert elicitation or from the 2002 PCSC.

72. The peer review panel considers that the engineering performance assessment work conducted to date under the Lifetime Programme has not fully captured the uncertainties associated with how the facility may actually perform and evolve over time. The SLC has been aware of our concerns for a relatively short time and has not had time yet to address them, but recognises this as an area for further work.

73. Our concerns include:

- That the set of parameter values used in the engineering performance assessment do not form a coherent set. This has partly arisen because after the elicitation workshop, the newly elicited parameter values were put together with values from the 2002 PCSC that had been derived on a different basis.

- That the recent elicitation process was not given sufficient time.

- That some rather optimistic assumptions were made, including:

    - that the vertical drains were assumed not to clog or fail;

    - that the permeability of the cap could be identified to within a rather narrow range, that did not take account of the potential for cracking as a result of differential settlement; and

    - that waters flowing into the facility (e.g., into trench 6) would be able to flow efficiently to the vertical drains on the other side of the trenches.

- That there appears to be considerable uncertainty in the degree of lateral flows into the facility from the surrounding geology, and from the facility into adjacent drift groundwaters (e.g., along the North West perimeter of Vault 8).

74. We are pleased, therefore, to see that the response made in submission to Requirement 2 recognises the need for optimisation of the repository design, based on a better flow model for the engineered system. We note that this model will need to link properly to the surrounding models of groundwater flow.

### 3.4.2 Source Term

75. The source-term model used in the current safety assessment is essentially the same as the one that was used in the 2002 PCSC (i.e., the DRINK biogeochemistry model). The model is applied consistent with various assumptions regarding the biogeochemical reactions that may occur in the disposal system. For example, assumptions are made regarding which solid phases present in the near-field will control chemical conditions and, thereby, influence radionuclide dissolution and speciation. Assumptions are also made regarding the production and 'fate' of gases. The peer review panel considers that the model appears to provide a reasonable representation of the aqueous chemistry of the system, but that further support may be needed for certain assumptions made regarding the gaseous phases, carbon dioxide and methane.

76. The main change in assumptions made since the 2002 PCSC has been as a result of some excellent work on the nature of the uranium bearing wastes disposed of to the trenches (Small *et al.* 2008). The peer review panel considers that this study has resulted in improved understanding of the nature of the wastes and their potential dissolution behaviour in the disposal facility. The study is particularly commendable in that it has taken the opportunity to access knowledge held by former staff of the Springfields plant that were involved in the fuel manufacture processes that led to generation of the wastes.

77. The effect of the recent work (Small *et al.* 2008) is that much of the uranium in the trenches is now believed to be in a form that would dissolve more slowly. The impact of the change to the uranium wastes source-term model is beneficial to (i.e., lowers) calculated doses and risks via the groundwater pathway but, as noted above, this pathway is now less important than it was believed to be in the 2002 PCSC. The impact of the change to the uranium wastes source-term model on doses and risks via other pathways should, of course, also be considered. It may mean, for example, that some of the uranium wastes are less readily dissolved into coastal waters following site destruction by coastal erosion.

### 3.4.3 Groundwater Flow

78. Section 4 of LLWR (2008e) describes a set of four different calculations (Cases A to D) undertaken to assess possible impacts from the groundwater pathway (see Table 4.1 of LLWR 2008e).

79. LLWR (2008e) recognises that, at this stage, not all conceptual uncertainties have been investigated, that an investigation of parameter uncertainties has not been carried out, and that although the calculation cases represent potential future conditions, they do not represent the possible evolution of the system with time (e.g. the evolution of the coastline).

80. The peer review panel acknowledges these quite significant caveats and considers that further work will be necessary in the lead up to the next safety case. For the next safety case we suggest that it would be sensible to focus in more detail on the following issues:

- Developing fully traceable documentation of the GoldSim assessment model, its testing and implementation.

- Describing how the GoldSim model is used in conjunction with the groundwater flow and transport models.

- Developing clearer more consistent links between the detailed hydrogeological modelling and the calculation cases used in the assessment. For example, it is not completely clear how the four calculation cases described in LLWR (2008e) relate to the five ‘future performance scenarios’ described in Section 5.1.2 of LLWR (2008d).

- Describing a realistic reference case. LLWR (2008e) focuses attention on Case A in which the engineering features are assumed to be performing as expected (no degradation) and which does not consider sea-level rise or changes in recharge.

- Terrestrial discharge. The more detailed work summarised in LLWR (2008d) indicates the possibility under some circumstances (increased sea level) of terrestrial discharges close to the mean tide line, but it is not clear from the submission that this has been captured in the assessment modelling.

- Improving the clarity and basis for any arguments made relating to the degree of hydrologic saturation in the near-field; the evidence and reality regarding suggestions of unsaturated conditions and perched water in the shallow parts of the groundwater system are presently vague.

- A better justification for the treatment of the water well. The peer review panel considers that some aspects of the current treatment of the water well are clearly conservative (e.g., the assumed presence and location of the well). However, we question whether it is reasonable to assume continuing regulatory control (e.g., under the Water Act 2003) over water abstraction after repository closure (see Section 4.5.2 of LLWR 2008e). LLWR (2008e) suggests that further work is needed to substantiate any claim that risks associated with the water well are consistent with the risk target, but it is not clear to the review panel what work is actually envisaged. We would caution against attempting to determine a quantitative *probability* for the drilling of a water abstraction well.

### 3.4.4 Coastal Erosion

81. LLWR (2008e) describes the approach taken for assessing the impacts resulting after erosion of the LLWR. The approach is a simplified one, which involves continuous erosion along a straight line '*erosion front*' parallel to the present day cliff. Calculated doses rely on the exposure assumptions.

82. The peer review panel considers that to support the identification of exposure pathways, there is a need for a better geomorphological description of the coast during possible erosion processes. As a result of developing such a description of how erosion might actually proceed, it is possible that additional exposure pathways may be identified that need to be assessed. For example, there might be periods of sea-level stability, or temporary sea-level falls, within the overall trend of increasing sea level, during which exposures might occur.

83. The peer review panel has also identified some aspects of the current assessment that appear optimistic, e.g:

    - The structure of model compartments may be too coarse to adequately represent radionuclide uptake by organisms in the intertidal zone.

    - The assumption that exposures in buildings constructed on the shore can be ruled out appears optimistic. We note that there is a need to assess potential exposures in buildings constructed by a lagoon (see figure 4.2 in LLWR 2008d).

    - The assumption that the recovery and re-use of waste materials would not lead to further exposures appears optimistic.

84. LLWR (2008e) acknowledges the fact that uncertainties exist, and indicates that further work will be conducted for the next safety case. The peer review panel supports this intention.

### 3.4.5 Radon and Thoron Doses

85. The safety assessment described in the submission made in response to Requirement 2 includes a new model for estimating doses from radon and thoron. This new model replaces the model used in the 2002 PCSC. The new model is best documented in Appendix B of LLWR (2008e).

86. Although the problems with the 2002 PCSC model are more clearly explained in the final version of the Requirement 2 submission than they were in earlier drafts, and the description of the background to the new model is generally good, it is not entirely clear how the present model has been derived from the data. The peer review panel considers that the new model needs to be fully and traceably documented so that it can be

thoroughly peer reviewed. This is important because doses and risks due to radon are the primary hazards between now and erosion of the site.

87. The peer review panel notes that most of the large variation in radon levels in dwellings (1 to 2 orders of magnitude) is not explained by the new model. We consider, therefore, that the new radon model has a rather low predictive capability for any particular situation, and that it would be necessary for the next safety case to fully acknowledge and address the uncertainties inherent in its use.

88. We note the SLC's stated preference for an empirical model (LLWR 2008e), but we consider that there may be benefit in making comparisons between the empirical model and process type models, particularly with the aim of allowing an analysis of uncertainties.

89. We are also uneasy about the apparent extent of averaging in the derivation of the new radon and thoron model, and we suggest that in the next safety case uncertainty should be assessed in a more explicit way; without this, further justification will be required for consideration only of an average case.

90. We also note that when applying the model to situations not involving human intrusion, it has been assumed that the cap performs well and that cracks do not allow more rapid release of radon from the waste.

91. Overall, therefore, we regard the new radon and thoron dose model and its results as provisional. We agree that further development, as suggested in LLWR (2008e), would be necessary if the new radon and thoron model is to be taken forward to the next safety case.

### 3.4.6 Human Intrusion

92. The SLC's approach to assessing human intrusion is summarised in Section 7 of LLWR (2008e). The human intrusion models used in the current assessment are based on those used in the 2002 PCSC, but some different assumptions and parameter values have been used in their current implementation.

93. The peer review panel supports the SLC's view that events which involve damage to the engineered barriers and/or penetration or excavation of the waste represent intrusion, whereas the drilling of a water abstraction well into a plume of contaminated water outside of the facility does not (see footnote 40 on page 84 of LLWR 2008e).

94. In the 2002 PCSC, BNFL's future human actions scenarios assumed that inadvertent human intrusion could occur at any time after the withdrawal of active institutional controls (BNFL 2002b). In the current safety assessment, various arguments are made regarding the probability of inadvertent human intrusion, including an argument that the probability

will be reduced as a result of passive institutional controls (LLWR 2005e, page 86).

95. While there is a reasonable logic for assuming that the probability of inadvertent human intrusion can be assumed to be zero during the active institutional control period, this is not the case for the period of passive institutional control. For example, IAEA draft guidance is that although the provision of passive institutional controls should be encouraged, safety assessments should not assume that passive institutional controls will be effective in preventing or reducing the probability of human intrusion (IAEA 2008). Consistent with draft IAEA guidance on safety assessments (IAEA 2008), we consider that when assessing potential doses associated with radioactive waste repositories, inadvertent human intrusion should be assumed to occur as soon as active institutional control ceases.

96. We consider that a reasonable range of intrusion scenarios has been identified and assessed, but note that the impact of waste heterogeneity and the consequences of inadvertent intrusion into localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides is more fully recognised and discussed more transparently in LLWR (2008a, b) than in LLWR (2008e).

97. For example, LLWR (2008a, page 48) reports that '*Intrusion into and then building a dwelling on average waste from Trench 3 (the Trench with the highest 226Ra inventory) would give a dose of 3 mSv yr$^{-1}$; for the worst contiguous 20 bays the dose would be 38 mSv yr$^{-1}$. Higher radiation doses could occur if the very highest concentration waste is built on. We consider, however, that such a case is very unlikely because of the size of excavation that is needed to penetrate to the waste depth, which implies that dilution and mixing is likely. It seems unlikely that an intrusion to 8m depth for the purpose of road construction would remove a small volume of waste to the surface and that a house would be constructed without significant mixing.*'

98. While it seems reasonable to take account of the thickness of the cap when assessing the consequences of an inadvertent human intrusion, we differ from the SLC's project team over the presentation of some of the arguments made regarding the *probability* of the inadvertent human intrusion event itself. We do not consider that quantitative credit should be taken in the safety assessment for passive institutional controls, and we also consider that it is too speculative to suggest a probability of inadvertent human intrusion after the lapse of passive controls (see pages 86 and 87 of LLWR 2008e). As noted by the ICRP (2000), there is no scientific basis for estimating the probabilities of future inadvertent human intrusion events.

99. LLWR (2008e) proposes that a reference level dose rate of 10 mSv/year should be used when considering impacts from inadvertent human

intrusion. The peer review panel considers that if the consequences of inadvertent human intrusion are to be compared against a dose-based intervention criterion of this type, then it is a form of double counting also to make arguments as to the low probability of the intrusion event[4].

100. If arguments are to be made regarding the probability of inadvertent human intrusion, then logically the assessed risk from intrusion should be compared to a risk-based standard (e.g., the risk target).

101. If calculated doses from inadvertent human intrusion are significant when compared to the relevant dose-based intervention criterion, then a stronger argument would be made for or against waste retrieval by focussing on the costs and other factors associated with retrieval, rather than by making arguments about the probability of intrusion events.

## 3.5 Quality Assurance and Use of Assessment Results

### 3.5.1 Quality Assurance

102. There is clear evidence that documents have been put through suitable QA processes, but some documents have been produced at too late a stage, and there has been little time for the SLC's project team to draw together the various different R&D and assessment studies into a coherent assessment to support the submission made in response to Requirement 2.

103. For the next safety case, we believe that there will be a need for more detailed documentation of safety assessment data and parameter values, and we recommend consideration of production of dedicated data reports such as SKB (2006).

104. As an example of the need for further detailed documentation, we have not seen detailed documentation of the GoldSim assessment model, or evidence of its verification or testing against the more detailed supporting hydrogeology models or against previous assessment models (e.g., those from the 2002 PCSC).

105. The peer review panel considers, therefore, that the safety assessment work could not be reproduced today by another suitably qualified team based on the documentation provided.

106. These issues are recognised by the SLC and will be taken into account in the planning of the forward programme for development of the next safety case. The issues are not significant for the submission made in response to Requirement 2 because the submission is an interim deliverable, and

4 We note that judgement has to be exercised when developing human intrusion scenarios (e.g., so that the illustrations considered are not wildly unrealistic), particularly those involving sequences of events each with their own probabilities. However, in this case it does not seem unreasonable behaviour for people in the future to construct a house or houses on excavated materials.

does not propose changes to the CFA, or come to firm decisions on facility design or site remediation.

### 3.5.2 Assessment Results

107. The peer review panel considers that the current assessment results help to indicate, in a general sense, which scenarios and exposure pathways are the most important and, therefore, where the emphasis for further assessment work should lie in the lead up to the next safety case. However, the limited range of uncertainty and sensitivity analyses carried out mean that it is not possible to be particularly specific as to where improvements might be made.

108. From a safety case perspective, the focus should probably be on ensuring that a rigorous, 'water-tight' assessment is made of the coastal erosion pathways, and of inadvertent human intrusion, particularly into localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides. There should also be further consideration of:

- Flows through the LLWR, taking account of facility degradation.
- The possibility of terrestrial discharge of contaminated groundwater near the coast, especially under conditions of increased sea-level.
- Bath-tubbing and engineering measures to prevent this.

109. We consider that it should be possible to make a reasonable qualitative argument that the drilling of a water well between the LLWR and the coast is unlikely.

### 3.5.3 Comparison with Regulatory Criteria

110. The safety assessment reported in LLWR (2008e) has led to some important developments in terms of understanding how the site may evolve, and the structure of the next safety case, but the peer review panel considers that for several reasons (uncertainty in which regulatory criteria apply, limited treatment of uncertainty in the assessment calculations, limited traceability of assessment data, etc) it would be premature to draw any firm conclusions from comparisons of the current assessment results (doses and conditional risks) with quantitative regulatory criteria.

# 4 Peer Review of Options Analysis and Proposed Site Strategy

## 4.1 Options Analysis – General Comments

111. The peer review panel considers that the SLC has carried out a useful study of options for future management of the trenches. One of the most positive aspects of the recent study, particularly as compared with previous studies (e.g., BNFL 2004), was the inclusion of local and other stakeholders in the process. This is an aspect that should be continued, not least because some of the local stakeholders may hold important information on waste disposals to the trenches.

112. Initially, the recent options study probably went into too much detail on remediation technologies (e.g., Amin 2007) and the ‘toolkit’, thus developed, was not sharply enough focused on the issues requiring management at the LLWR.

113. The ‘threats’ to the safety performance of the LLWR were identified as (i) facility destruction by coastal erosion, (ii) inadvertent human intrusion, (iii) releases via groundwater, and (iv) releases via gas. These threats were reviewed and discussed with stakeholders, and in doing so were given roughly equal emphasis by the SLC’s project team. Local stakeholders tended to focus on the threat of ‘leaks’ via groundwater. This raises the question of how well stakeholders understood the nature and relative importance of the different pathways leading to risk, and whether adequate information was provided. In our view, the greatest emphasis should have been placed on the first two threats, i.e., coastal erosion and inadvertent human intrusion.

114. A reasonable set of options was considered in the study (see Section 4.2), but there was a lack of clarity over the definition of some of the options and this was particularly the case for the ‘Bulk or Local [waste] Retrieval’ option. The lack of clarity over the waste retrieval options could have been resolved by using some of the detailed information on the spatial heterogeneity of the wastes in the trenches to define the scale of waste retrieval envisaged. In particular, it would be possible to identify particular localised volumes of waste in the trenches possessing relatively higher concentrations of long-lived radionuclides (see figures 1 and 2 of Lennon 2007), and examine the pros and cons of different options for their management.

115. The recent options analysis study did not include a quantitative scoring of the options against defined attributes. Currently, the peer review panel considers that the basis for implementing some options while rejecting others needs to be further clarified and strengthened. While we recognise that quantitative scoring can only provide a guide to decision-making, we consider that, in order to demonstrate that risks are ALARA, there needs to be a new quantitative evaluation of the costs and benefits (e.g., in terms

of risk reduction) of options defined using the latest information on the spatial distributions of wastes in the trenches.

116. The financial cost of an option, in particular, will depend on the scale at which it is applied and, for example, retrieval or *in situ* remediation of a small amount of waste will likely be cheaper than for a larger amount. At present it is not clear how the risk reduction benefits of groundwater cut-off walls and vertical drains, compare to those of localised waste retrieval and, therefore, why cut-off walls and vertical drains are considered a ‘better buy’ than selective waste retrieval.

## 4.2 Proposed Site Strategy

### 4.2.1 Options for the Trenches

#### 4.2.1.1 Retrieval of all Trench Wastes

117. The peer review panel considers that the SLC is correct to conclude that retrieval of all of the trench wastes for re-disposal elsewhere would be a costly exercise. We also recognise that this would pose a major issue for national LLW management strategy.

#### 4.2.1.2 Retrieval of Wastes to Reduce Average Specific Activity

118. The peer review panel considers that the option of attempting to retrieve some of the wastes from across each of the trenches in order to reduce the average specific activity of the remaining wastes (see Section 7.2 of LLWR (2008a) is a rather hypothetical one. The peer review panel is not aware of any regulatory or other pressure to consider such an option. The peer review panel also notes that long-lived radionuclides, which are the parents of radon and thoron, are widely distributed within the trenches, such that it would not be easy to selectively remove all of the long-lived radionuclides. We agree, therefore, that such options should not form part of the strategy for the LLWR.

#### 4.2.1.3 Retrieval of Localised Wastes

119. We agree with the SLC that further analysis is required to determine where the balance lies between the pros and cons of retrieving certain localised volumes of waste in the trenches possessing relatively higher concentrations of long-lived radionuclides. Although there are uncertainties in the dose assessments, it seems that some relatively small volumes of waste in the trenches could give rise to calculated doses of several tens of mSv and possibly more than 100 mSv under some scenarios. There are also further considerable uncertainties related to the regulatory criteria, and to the costs and risks of waste retrieval. In our view, the issue of localised waste retrieval needs to be assessed in more detail, with much greater transparency, and with specific reference to

particular localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides.

#### 4.2.1.4 *In-situ* Remediation

120. For various reasons, including cost, the peer review panel agrees with the SLC's assessment that the '*In-Situ* Remediation – Vitrification' option is not appropriate at the LLWR.

121. We also agree that the '*In-Situ* Remediation – Grouting' option would have only a limited effect in reducing the impacts from human intrusion or coastal erosion, and we consider some of the purported benefits of *in-situ* grouting (e.g., reducing radionuclide solubility – see page 68 of LLWR 2008a) to be largely irrelevant in this context.

122. In addition, we note that there might be difficulties in demonstrating effective implementation of such *in-situ* remediation techniques.

### 4.2.2 Institutional Control

123. The IAEA defines LLW as '*waste that is suitable for near-surface disposal'*, and suggests that the concentrations of long-lived radionuclides that can be accepted in LLW are limited by the time period over which near-surface disposal can ensure the isolation of the wastes and can prevent inadvertent human intrusion.

124. We consider that it would be sensible to aim to provide active institutional control for as long as possible given that[5]:

- The LLWR already contains relatively high levels of long-lived radionuclides as compared with wastes classified as LLW internationally and in some other countries (and assuming that these wastes are not retrieved for disposal elsewhere).

- Current plans are to continue to dispose of long-lived wastes in the vaults.

125. Assuming that it ought to be possible in the UK to provide active institutional control for at least 300 years, we agree with the SLC's statement that active institutional control should be provided for as long as can reasonably be achieved (page 68 of LLWR 2008a).

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[5] Within the radioactive waste disposal literature, 300 years has often been suggested as a reasonable estimate of the length of time for which it may be possible to rely on active institutional controls. The period of 300 years coincides approximately with ten half lives of the relatively active, but short-lived radionuclides, Cs-137 and Sr-90. Thus, the provision of active institutional controls for 300 years (which could be assumed to prevent inadvertent human intrusion), enables the disposal of relatively active but short-lived wastes at or near the surface.

### 4.2.3 Coastal Defences

126. The peer review panel considers that the SLC is correct to conclude that the disposal facility should not be reliant on coastal defences for protection from erosion in the long-term (i.e., for timescales relevant to long-lived radionuclides). Unless sufficient funds were set aside by the present generation for use in the future, such reliance would place undue burdens on future generations who would have to pay to maintain the coastal defences, but who would not have benefitted from the processes that produced the wastes.

127. In contrast, the peer review panel notes that the submission made in response to Requirement 2 is rather tentative regarding the possibility of protecting the site from inundation in the shorter-term (see page 66 of LLWR 2008a); we consider that the possible need to prevent flooding should be kept under active review.

### 4.2.4 Engineered Features

#### 4.2.4.1 Cap

128. The peer review panel considers that the SLC is correct to conclude that construction of a final cap over the wastes is best practice in near-surface radioactive waste disposal, and should form part of the strategy for the LLWR.

129. The peer review panel suggests that the SLC should consider a staged programme of cap construction because this would provide an opportunity to trial and improve the cap construction process, to monitor cap performance, and to gather data on which to base models of cap performance.

#### 4.2.4.2 Other Engineered Features

130. As discussed in Section 3.2.2, the peer review panel is not fully convinced by the justifications provided for the vertical drains, the vault base liner, or the cut-off walls. Collectively these features (together with the cap) are designed to prevent '*bath-tubbing*' and terrestrial discharge.

131. In terms of best practice, we note that the submission has not identified an example of a near-surface radioactive waste disposal facility with an impermeable concrete vault base and liner. Also, the use of drains for improving *long-term* performance appears novel – the text of LLWR (2008b) sometimes compares the vertical drains with the much more common operational drainage systems at other LLW disposal facilities, but this comparison can be misleading.

132. The peer review panel considers that the avoidance of bath-tubbing and terrestrial discharge should be a key design aim, but we are yet to be

convinced that the proposed system will achieve this. For example, we are not convinced that with their current proposed design, the vertical drains would continue to operate for the required period and would not become clogged. The peer review panel considers that a simpler facility design with a permeable vault base might be better.

### 4.2.5 Radiological Capacity and CFA of Waste

133. Given the various uncertainties that exist (e.g., surrounding which regulatory criteria to apply, the interim nature of the current safety assessment, and the on-going LLW strategy development process), the peer review panel agrees with the SLC that it is correct not to make firm decisions at this time on the establishment of new radiological capacity limits or conditions for waste acceptance of waste.

# 5 Conclusions

## 5.1 Peer Review

134. The peer review panel considers that the submission made in response to Requirement 2 and provided to the EA on 1 May 2008 had improved considerably in the time since the peer review panel reviewed the work in early April 2008. Many of the changes and developments have resolved peer review comments, and the SLC's project team has acknowledged the benefit provided by the peer review.

135. Inevitably and appropriately some peer review comments and issues remain to be dealt with. The SLC has indicated that it is planning further work to address the remaining issues in the lead up to the next safety case.

136. Peer review is an ongoing process and will need to continue throughout the programme leading to the next safety case. Planning of peer review activities needs to be an integral part of planning for the programme leading to the next safety case.

## 5.2 Addressing the Requirements

137. The peer review panel considers that the submission has certainly provided a wide range of information that goes well beyond the original wording of Requirement 2 as stated in the Authorisation.

138. The submission includes the outcome of a wide-ranging risk management study and addresses many issues relevant to the radiological capacity of the site. The submission does not demonstrate that risks are ALARA, but it does indicate a firm commitment to the next safety case and to making a robust ALARA demonstration. This seems appropriate given the various uncertainties that exist.

## 5.3 Proposed Strategy

139. With regard to the strategy being proposed for the LLWR, the peer review panel agrees with the SLC that:

- A final site cap will be essential.
- A period of active institutional control after waste disposals cease will be essential.
- Coastal defences cannot be relied on to protect the LLWR from erosion in the long-term (i.e., for timescales relevant to long-lived radionuclides).

- The pros and cons of retrieval from the trenches of localised volumes of waste possessing relatively higher concentrations of long-lived radionuclides need further analysis.

140. In April 2008, the peer review panel suggested that SLC should not be definite on the need for the vertical drains, the vault base liner, or the cut-off walls – this is still our view. These features are still part of the proposed strategy, but the submission and the SLC recognise the need for further optimisation of the design, and we support this.

141. Overall, therefore, the peer review panel is now more comfortable and able to support the main conclusions on strategy proposed in the submission.

## 5.4 Forward Programme

142. We have made various detailed technical suggestions in Section 3 and 4 regarding issues that could be considered in the forward programme leading to the next safety case. Here we highlight just a few key points:

- There is only a short period in which to develop the next safety case. Simply documenting the safety case might take a year towards the end of the period. Good planning will be essential if the various components of the safety case are to be brought together at the right time and with appropriate levels of consistency, quality assurance and peer review. It would seem sensible, therefore, for the SLC to maintain the valuable momentum developed during recent months.

- The next safety case will need to include a safety assessment that includes a more comprehensive treatment of uncertainty. Planning the approach to the treatment of uncertainty should probably be one of the more strategic issues that should be considered at an early stage.

- There is a need to better integrate the engineering design and optimisation work with the safety case. Decisions on facility operation should be checked for consistency with the environmental safety cases.

- The risks from coastal erosion of the facility need to be assessed in a thorough and robust way.

- A more convincing and well-supported understanding of groundwater movements and potential radionuclide transport should be demonstrated in order to confirm that ground and surface water pathways are now a less prominent issue in long-term performance.

- The issue of localised waste retrieval needs to be assessed with much greater transparency, in order that risks can be shown to be ALARA.

- The implications of coastal erosion for the suitability of the site for near-surface radioactive waste disposal should be considered further with regulators and stakeholders.

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## Appendix 1 – The Peer Review Panel

### Dr David Bennett

181. Dr David Bennett (BSc., PhD., FGS) is Director of TerraSalus (EarthSafety) Limited. He has over 17 years experience in providing strategic and technical consultancy advice on radioactive waste management and its regulation. He is a geologist and geochemist, and has contributed to over 60 published papers and reports in the area of radioactive waste management.

182. His specialities include disposal facility authorisation and licensing, regulatory review and interpretation, peer review, risk and safety assessment, safety case development, engineered barrier systems, radioactive waste immobilization, and geochemical and radionuclide transport modelling. He has also contributed to a range of consultative BPEO studies and options appraisals on waste management and disposal.

183. Dr Bennett has contributed to radiological assessments and nuclear waste management programmes in Belgium, Finland, France, Germany, Japan, Sweden, the UK and the US, and has also contributed to several international programmes run by the European Commission, the International Atomic Energy Agency (IAEA) and the OECD Nuclear Energy Agency (NEA).

184. Dr Bennett currently chairs the independent peer review panel that is reviewing the development of new safety cases for the LLWR near Drigg. He is also secretary to the international BRITE group, which is reviewing near-field aspects of the Swedish spent fuel disposal programme on behalf of the Swedish Radiation Safety Authority. Dr Bennett is lead consultant to the NEA for its Engineered Barrier System (EBS) project, and has recently contributed to an international peer review of the Electric Power Research Institute (EPRI)'s assessment capability for radioactive waste disposal at Yucca Mountain in the US. Dr Bennett has also been assisting the IAEA to develop a new Safety Guide on safety cases and safety assessments for radioactive waste disposal.

### Dr Adrian Bath

185. Dr Adrian Bath (BSc., PhD., CGeol) is Director of Intellisci Limited. He has over 33 years experience as research scientist in groundwater chemistry, hydrogeology, and environmental chemistry, and 24 years experience in applying geochemistry in radioactive waste management, the environmental behaviour of radionuclides, and safety assessment of waste repository sites. He is also a member of the US Geochemical Society, of the International Association of Hydrogeologists, and of the International Association of Geochemistry.

186. He specialises in environmental geochemistry and contaminant chemistry in groundwaters, the surface environment and engineered systems, and provides services for clients in radioactive waste management, hazardous waste management, environmental remediation, water resources and environmental quality. He has authored many scientific publications and consultancy reports on the applications of geochemistry in radioactive waste management and in other areas of groundwater and environmental science.

187. His experience includes:

- Providing scientific advice and services to European, American and Japanese radioactive waste management and nuclear regulatory organisations.

- Planning and interpretation of site investigations for repositories and underground laboratories in crystalline rock and clay rock.

- Geochemical modelling of radionuclides in engineered barriers, groundwater systems around repositories, and in contaminated construction materials.

- Specialist problem-solving for projects concerning hazardous waste management, landfill disposal, groundwater contamination and geotechnics.

- Scientific management and review activities in projects on hydrogeochemistry, isotope hydrology, groundwater flow, solute transport, palaeohydrogeology and groundwater and soil contamination.

## Prof. George Fleming

188. Professor George Fleming (BSc., PhD., FREng., FICE., FCIWM., CEnv) is Managing Director of EnviroCentre Limited, and Emeritus Professor of civil engineering at Strathclyde University. His research publications include contributions to 15 books and over 250 publications in journals, keynote addresses, papers at conferences, reports, plus the production of 4 video documentaries and a permanent exhibition.

189. He specialises in environmental management, including hydrology and water and soil resources engineering, where he has pioneered the development of computer aided design and simulation techniques. He has undertaken research into the uses of dredged material, landfill hydrology, real-time drought and flood forecasting, river basin management, land-use, and river engineering for fishing improvements. He currently leads a major trial to manage contaminated dredgings in the North Sea.

190. Professor Fleming has acted as consultant to many national and international organisations, including the United Nations FAO, IAEA, ILO, WMO; agencies such as the Scottish Development Agency, Highland and Strathclyde Regions, Monklands, Inverclyde, Dundee, Clydebank, Lochaber, Glasgow and Annandale and Eskdale District Councils; the SSEB and CEGB; and a number of private companies including Jacobs Babtie, Binnie & Partners, Mott MacDonald, EPDC, Bovis, Wimpey Waste, Clydeport Ltd, Patersons of Greenoakhill, Peel Holdings and Port of Tyne.

191. Significant projects include dams in Kenya, Labuan and Brunei; Strathclyde Park; flooding in Sutherland; numerous landfill sites; Glasgow Garden Festival Project; Dinorwig Power Station Project; reservoir management in the Alps; flood control in California, Chicago and Brazil.

192. Professor Fleming was appointed to the DTi's Overseas Projects Board in June 1991, and to the Boards of the Scottish International Resource Project and to the Scottish Exports Forum in 1996. Professor Fleming was elected to the Council of the Royal Society of Edinburgh and served as Convenor of the Royal Academy of Engineering in Scotland for eight years. Professor Fleming was President of the Institution of Civil Engineers in 2000, and served on various boards and committees. Following the completion of his Presidency, he became Chairman of the ICE Waste Management Board and is still heavily committed to Engineers Against Poverty (formerly The Telford Challenge).

### Dr Graham Garrard

193. Dr Graham Garrard (BSc., MSc., PhD., CGeol) is an Associate Director of Halcrow Group Limited. He has over 27 years experience in engineering geology and geotechnics, with extensive experience in the management of major projects in the UK and abroad, including risk assessments, feasibility studies and investigations for nuclear facilities, road and pipeline developments, waste disposal sites. His experience includes:

- Geotechnical Team Leader and Deputy Design Manager for the Dounreay Shaft Isolation Project.
- Project Manager for several programmes involved with the design and assessment of engineered barriers for low-level nuclear waste.
- Team Leader responsible for geotechnical studies using systematic risk assessment methodologies to help quantify the possible risk from barrier failure in low-level nuclear waste landfills and from cavernous ground.
- Project and Resident Engineer for a seismic hazard assessment and geotechnical studies for a nuclear power station, including design

and supervision of a state of the art site investigation with a project value of approximately £2.2 million

- Conducting independent technical assessments of site investigations on behalf of the Department of Environment (old limestone mines in the West Midlands) and DML (Devonport nuclear submarine refit facilities) and having designs audited by regulatory authorities.

### Dr David Holton

194. Dr David Holton (BSc., PhD., FGS) is Manager of Serco Limited's Waste Management and Environment Business. He has over 18 years experience in hydrogeology and mathematical modelling of contaminant and radionuclide transport. His key skills include:

- Project management and technical leadership of projects in the nuclear industry internationally.

- Overall management of the use of various software tools to evaluate the impact of radioactive waste as part of site investigation and interpretation work.

- National and international expert reviewer (on behalf of the IAEA, POSIVA, ANDRA, KAERI, State of Nevada, Mont Terri Consortium, member of the NERC Peer Review College).

- Developer of methodologies for the integration of site understanding.

- Expert in hydrogeology, hydrogeological modelling (including interpretation of hydraulic testing, integration of BIPS and other geological information, point dilution and testing tracer testing), environmental risk assessments, groundwater flow and radionuclide transport.

- Experience of communicating technically complex issues to a very wide range of technical stakeholder groups from Universities, Agencies (Environment), Radioactive Waste Management Agencies, IAEA in a range of different forums, to workshops and international conferences.

- Expert technical author. He has produced over 100 technical reports and peer reviewed papers.

### Prof. Steve Jones

195. Professor Steve Jones (BA., PhD) is Principal Consultant at the Westlakes Research Institute. He is also an Honorary Professor of Environmental and Occupational Toxicology, at the University of Central Lancashire, and

is a Visiting Professor at the Industrial Ecology Research Centre, at the University of Liverpool. He has over 16 years experience at senior level in industry and as a consultant, largely concerned with the assessment and management of environmental issues and the interactions between business needs, scientific issues and understanding, legislation and regulatory policy, public and political expectations.

196. He is an invited independent member of the National Dose Assessment Working Group, concerned with methodologies for assessing doses to the public from radioactivity in the environment. He acts as peer reviewer for many scientific journals in the fields of radiation protection, dosimetry, radioecology and occupational medicine

197. His experience includes:

- Direction of industrially focused R&D in the environmental and life sciences.
- All aspects of practical health physics, including radioactivity measurement, dose assessment, environmental monitoring, occupational exposure control, discharge assessment and emergency preparedness.
- Interpretation of occupational and environmental epidemiological data.
- Preparing environmental assessments and working with environmental legislation and regulators to negotiate authorisations and consents.
- Development of environmental policy and related environmental management systems, and conducting environmental liability reviews in relation to due diligence.
- Legally-related scientific work, both as scientific advisor and an expert witness, in both civil and criminal proceedings, together with judicial review and public inquiry work concerned with environmental impact issues.
- Participation in BPEO, MADA and related environmental decision-making processes, involving stakeholder dialogue and concerns about environmental performance and safety.
- Acting as an expert for the FCO in relation to actions against the UK Government in respect of Sellafield’s discharges to the Irish Sea.
- Contributing to the development of integrated waste strategies for nuclear sites.

- Participating in collaborative European research projects on protection of the environment from ionising radiation.