ASSESSMENT OF THE GENERIC DISPOSAL SYSTEM SAFETY CASE

CoRWM Position Paper

EXECUTIVE SUMMARY

1. The Committee on Radioactive Waste Management (CoRWM) has carried out an assessment of the generic Disposal System Safety Case (gDSSC) published by the Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA) in February 2011. The assessment covered the whole suite of gDSSC documents, and related RWMD reports on research and development (R&D) and site characterisation.

2. From its assessment of the suite of safety case documents, CoRWM concluded that, in general, the gDSSC shows that RWMD's understanding of the scientific and technical knowledge underpinning geological disposal is sufficiently comprehensive for the current stage of its work. CoRWM identified some topics for which it appears that RWMD's understanding and ability to use knowledge will need to be increased before any site specific DSSC is produced. However, the Committee believes that it will be straightforward for RWMD to make any improvements that are required. CoRWM also concluded that RWMD has, or will have, appropriate processes in place to fill gaps in its knowledge through R&D. CoRWM concluded that RWMD's site characterisation strategy and plans are not yet comprehensive but that they are developing in appropriate directions at this stage of the implementation of geological disposal.

INTRODUCTION

Background

3. This paper presents the CoRWM assessment of the generic Disposal System Safety Case (gDSSC) produced by the Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA). The gDSSC includes all the reports and documents included in the CD-Rom "Geological disposal Issue 02-2011", and referred to and listed in the overview document (RWMD report 010), where the hierarchical structure of the gDSSC document suite is also set out.

4. The assessment also considers three additional documents with which the gDSSC necessarily interfaces: RWMD's Technical Strategy (report 075), the Site Characterisation Status Report (report 057), and the Strategy for Site Characterisation (report 017). All the RWMD documents considered by CoRWM in its assessment are listed in Annex 1.

5. The assessment was carried out at the suggestion of the Department of Energy and Climate Change (DECC). It is part of CoRWM's work on its principal task, which is to provide independent scrutiny and advice on Government and NDA proposals, plans and programmes to deliver geological disposal, as the long-term management option for most of the UK's higher activity radioactive wastes.

Objectives

6. CoRWM's objectives in assessing the gDSSC suite of documents were to determine whether RWMD:
   - has a sufficiently comprehensive understanding of the scientific knowledge underpinning geological disposal;

- is making full use of this knowledge in its work on the implementation of geological disposal, its development of a DSSC, its planning for site characterisation and its design studies for a geological disposal facility (GDF);
- has in place processes to identify and fill gaps in its knowledge on appropriate timescales (where the judgement on "appropriate" takes into account whether the knowledge gap needs to be filled on a generic, rock-type-specific or site-specific basis).

Scope

7. While the assessment covered the whole gDSSC suite, CoRWM did not review all the reports in detail. The main focus was on assessment of:
   - the extent to which the gDSSC inspires confidence that RWMD has the structures and processes in place to enable it to characterise a site, design a GDF, and make a satisfactory safety case with an appropriate balance of qualitative and quantitative arguments;
   - RWMD's approach to identifying research and development (R&D) requirements for the implementation of geological disposal;
   - RWMD's site characterisation strategy.

Relationship to Regulators' Review

8. The Environment Agency (EA) and the Office for Nuclear Regulation (ONR) have carried out a regulatory review of the gDSSC (EA and ONR, 2011). CoRWM held discussions with EA and ONR before starting its review, with the objective of understanding the regulators' approach and avoiding any unnecessary overlap. The Committee then worked independently and completed most of its assessment of the gDSSC before the regulators published their review report.

9. The purpose of the regulators' review was to (EA and ONR, 2011):
   - identify whether there are any fundamental issues that would prevent a safety case for any GDF being made in future;
   - make recommendations for RWMD to consider when developing any future safety case;
   - assist the regulators in providing information and advice to Government and stakeholders;
   - determine whether the gDSSC meets regulatory expectations, as set out in their guidance (HSE, 2008; EA and NIEA, 2009).

10. Although the regulators' review had a different purpose and objectives, on some topics it makes points that are similar to CoRWM's. Where this is the case this is noted in CoRWM's commentary in Annex 2. There are no topics on which the regulators and CoRWM have reached conflicting conclusions.

Factual Checking of Draft

11. This paper has been produced through a combination of offline member reading and assessment of individual reports and documents and online discussion and integration of these assessments. The latter has involved discussions within CoRWM at plenary meetings (May, June, August and November 2011) and in dedicated task meetings (October and December 2011). The content has been checked for factual accuracy with RWMD, EA, ONR and DECC.

Layout of Paper

12. The paper begins with comments on the structure of the gDSSC document suite and the processes used by RWMD in developing it, particularly internal and external reviews. The following sections contain the principal results of CoRWM's assessment of the gDSSC and its views on RWMD's future work. These sections are approximately aligned to the bulleted points noted under the objectives and scope of the assessment (paras. 6 and 7). Annex 2 contains a more detailed commentary on the gDSSC and should be consulted to gain a fuller understanding of the basis for the principal results of the CoRWM assessment, as well as for additional CoRWM comments on gDSSC documents.

DEVELOPMENT AND STRUCTURE OF gDSSC DOCUMENTS

Document Development and Peer Review

13. RWMD's general processes for document development and peer review are described in its Technical Strategy (report 075). CoRWM has also been informed by RWMD of the document development, quality control and review processes and procedures specifically applied to the gDSSC suite.

14. In general, CoRWM considers that these processes are satisfactory. However, it would be helpful if, in future, specific details were given in DSSC documents. It is suggested that each DSSC document should show:
    - its author(s);
    - when and by whom it was reviewed, internally and externally.

15. It would also be preferable to make clear the means of accessing and interrogating the comments and change logs for each document. These measures are important for transparency and for building confidence that enough people of sufficient expertise and experience are involved in carrying out and reviewing RWMD's work.

16. CoRWM acknowledges that there are problems in obtaining well-qualified and yet independent peer review of material such as the gDSSC. CoRWM commends RWMD for its attempts to obtain such review of the higher level documents, but suggests that future versions of the DSSC and supporting reports clearly describe the assessment and review processes used to underpin the final documents. The quality management process should be clearly distinguished from the independent peer review process.

Document Structure

17. RWMD explained to CoRWM that it wished the gDSSC documents, particularly the Status Reports, to be standalone. There is thus repetition within and between the gDSSC documents. However, there are some differences in the repeated material, which means that readers of the whole suite cannot bypass it. This approach also has the potential to lead to inconsistencies. It would have been better to have a common introductory section in each document that is clearly marked as such.

18. Although the hierarchical structure of the suite is explained in the gDSSC documents, there is no "map" that sets out where material on various topics can be found. As a result, readers may have to search the contents lists of several documents in order to find what they are looking for. It would have been helpful to have provided an overall index or electronic search facility.

RWMD'S UNDERSTANDING AND USE OF KNOWLEDGE

Demonstration of Understanding

19. The gDSSC Status Reports and higher level documents demonstrate that RWMD has a sufficiently comprehensive understanding for present needs, either in-house or through appropriate and well-considered commissioning of work by external contractors, of the technical and scientific knowledge underpinning geological disposal in most, though not all, relevant subject areas.

20. Those topic areas in which RWMD has demonstrated sufficient understanding for present needs are: package performance in accident conditions, package evolution in a GDF, near-field evolution and behaviour, radionuclide behaviour in groundwater, gas generation and migration, and criticality. CoRWM has confidence that RWMD is an intelligent client for R&D in all these areas, and is able to utilise contractors' work effectively and with considered judgement.

21. This is not to say that there are not gaps in the demonstrated understanding in these topic areas, and areas in which future safety cases will need to demonstrate understanding in a greater level of detail and depth. Criticality work, for example, does not yet cover UK spent fuels in enough detail. For waste package accident performance, the demonstrated understanding does not cover aged packages, recently developed packaging options, or flooding. However, the reported work in both areas gives confidence that such understanding can be readily developed before future safety cases are prepared for later stages in the Managing Radioactive Waste Safely (MRWS) process (Defra *et al.*, 2008).

22. The principal topic areas in which RWMD's understanding has not yet been demonstrated to be sufficiently comprehensive are the characteristics and evolution of geological barriers, and groundwater movement as a function of time after disposal of wastes in a GDF[1]. There are a number of reasons why CoRWM takes this view.

23. In the gDSSC, RWMD places all potential host rocks for a GDF in three, very broad categories: 'higher strength', 'lower strength sedimentary' and 'evaporites'. CoRWM considers that this compromises the ability of the gDSSC to convey RWMD's understanding of the geological barrier. CoRWM recognises the difficulties in providing a generic description of the geological barrier and its functions but it believes that RWMD could have chosen a better approach. In particular, qualitative consideration of a suite of examples of GDFs in different host rocks would have demonstrated more effectively that RWMD understands thoroughly the potential range of characteristics and behaviour of the geological barrier.

24. Another aspect of the geological barrier for which the gDSSC does not demonstrate that RWMD has enough understanding is that of coupled thermal, hydrogeological, mechanical and chemical (THMC) perturbations induced by a GDF. This is surprising given the involvement of RWMD in such international research projects as DECOVALEX[2], which, though cited in the Geosphere Status Report, is not described in sufficient detail to show the level of understanding achieved. The gDSSC suite could have more clearly demonstrated RWMD's understanding of the measurement, modelling and predictive techniques available for quantitative assessment of THMC processes.

[1] RWMD, in common with many waste management organisations in other countries, uses the term "geosphere" to cover all these topics. CoRWM only uses "geosphere" in the way it is used in the Earth Sciences and considers that RWMD would be better served by the use of 'geological barrier' instead.
[2] Development of Coupled THCM Models and their Validation against Experiments. This is a long-running international project, in which the UK has been involved for many years.

25. The characterisation, modelling and prediction of patterns and rates of groundwater movement in the geological barrier are vital to development of a GDF post-closure safety case. Its starting point is the use of site characterisation data to define and validate a conceptual and a numerical model of present groundwater movement. The generic assessment undertaken by RWMD in the gDSSC shows that the appropriate capability exists in other organisations but does not demonstrate that RWMD itself has the capability to undertake the detailed conceptual and numerical modelling of groundwater movement required in a site-specific DSSC.

26. Another topic area for which the gDSSC does not adequately demonstrate that RWMD has, at present, a sufficiently comprehensive understanding is the characteristics and evolution of the biosphere. The RWMD approach to the biosphere is the conventional one, which is based on defining reference biospheres linked to assumed climatic conditions and calculating radiation doses to reference people and other reference organisms. The international background to the approach and the assumptions underlying it are not clearly explained in the gDSSC. As a result, CoRWM was unable to assess from the gDSSC whether RWMD understands its rationale and limitations. The gDSSC also does not show that RWMD is aware, or taking steps to make itself aware, of developments in the modelling of future environments that could necessitate improving its biosphere approach in future safety cases.

Engendering Greater Confidence

27. The gDSSC suite represents a starting point for a process of documentation, synthesis and integration that will evolve. This context should have been made clearer, as in this initial state it can be seen as simply endorsing the well-documented international consensus of opinion that geological disposal can be shown to be safe at a generic level. It would have been helpful to include an explanation of the process by which this generic work will be used in developing a site-specific DSSC as the MRWS process progresses.

28. The gDSSC suite of documents is intended to be a formal statement of RWMD's knowledge supporting structured safety case arguments. An important part of a safety case for a GDF is a demonstration that the developer has a strong culture of safety and environmental protection, within an appropriate management framework. This is essential for public confidence, as well as being a regulatory requirement for all nuclear site licensees (HSE, 2008; EA, 2010) and for a GDF specifically (EA, HSE and DfT, 2011).

29. The gDSSC does not explicitly address how safety and protection of the environment is embedded in RWMD's general way of working but rather focuses on specific regulatory requirements for a GDF and for transport. It is suggested that future DSSC document suites should contain, at the outset, information on the management framework and safety and environmental protection culture in RWMD and in its supply chain.

30. Another way in which RWMD could engender greater confidence is by demonstrating strongly familiarity with other GDF safety cases and how those have been constructed. Several examples of safety cases exist worldwide (*e.g.* in the US, safety cases for the Waste Isolation Pilot Plant (WIPP) and for Yucca Mountain; in Sweden the SKB safety case; in Finland the Posiva safety case; in Germany the case for Gorleben; in Switzerland the case for a GDF in Opalinus clay; in France the case for a GDF in Bure mudstone). It would be of considerable value to summarise these cases, draw lessons from them, and show how these impact on RWMD's approach. Where available, reference could also be made to regulatory and international reviews of these safety

cases. If this had been done in the gDSSC it would have provided more evidence to underpin RWMD's confidence that overseas knowledge can be applied for a UK GDF.

31. CoRWM also considers that improved accessibility of DSSC documents would engender greater confidence that RWMD has the structures and processes in place to enable it to make a satisfactory safety case. CoRWM notes that the regulators have commented on the need to make future DSSC documents more accessible to a wider range of readers (EA and ONR, 2011), and understands that RWMD has plans to act on the regulators' comment.

Knowledge Management

32. As the implementation of geological disposal progresses, the information in the gDSSC suite will be used by RWMD staff and contractors who are not the authors of the gDSSC documents. It is thus important that the bases for the documents and their formulation are well-described and can be tracked. CoRWM was therefore pleased to learn from RWMD that it is in the process of developing its knowledge management procedures. It is essential that this is given a high priority, and the Committee welcomes RWMD's commitment to this.

33. In developing its knowledge management procedures, RWMD will need to pay particular attention to how knowledge as a whole, and not simply data, can be retained over decades, with changes in personnel at RWMD and in its supply chain. It is also important that the right knowledge is retained. The knowledge management process needs to have a clear audit trail that can track back to original sources and limitations on the underpinning data.

34. In general, the gDSSC does not do this but makes extensive use of contractors' reports as references. These reports are in many instances derivative, referring to other contractor reports rather than to primary data sources. RWMD in its future DSSC work needs to make clear its interpretation of the contractors' or original data, demonstrate that it has an understanding of any limitations of the data, and justify how any conclusions are arrived at. This would provide confidence that assumptions and data are being used with full knowledge of the context in which they were originally derived.

35. Ideally, all documents referred to in future DSSC documents would be available to the public *via* an online document store. CoRWM understands that RWMD plans to make available *via* the NDA website its referenced material, including Nirex, RWMD and other reports. It would be helpful if the website also provided full references to articles published in the scientific literature, so that they can be readily obtained.

36. CoRWM notes the importance of the current gDSSC Status Reports in terms of setting knowledge baselines. Work on safety cases beginning now will not come to completion for many decades. For continuity it is important that the background knowledge, including but not restricted to that provided in the Status Reports, is managed properly so that future safety cases do not keep rediscovering the same problems or issues.

37. While information management and record keeping are part of what is needed, these are relatively straightforward. More challenging is knowledge management in the sense of capturing and making transferable that knowledge which resides in the expertise and experience of former and present staff within RWMD and project-based employees and contractors. The documents assessed by CoRWM do not indicate the type of strategy that RWMD might adopt to recover and manage such knowledge, nor what procedures will be used to do so when knowledge transfer needs are identified. CoRWM considers this to be an important gap in RWMD's current Technical Strategy.

Quantitative Post-Closure Safety Assessment

38. The gDSSC includes calculations of health risks to people *via* the groundwater pathway and calculations of doses to people who inadvertently intrude into a GDF after closure. These calculations are stated to serve a number of purposes, including informing RWMD's disposability assessments for proposed waste packages, focusing R&D and providing an input to GDF design. There are no new calculations for gas generation and migration in the DSSC, although reference is made to previous calculations.

39. While CoRWM welcomes the inclusion of these calculations, it considers that the gDSSC places too much emphasis on the results, particularly those for the groundwater pathway. The modelling approach for the groundwater risk calculations is very simple and the sensitivity analyses limited. In addition, the assumptions about rates of release from waste packages are not self-consistent (for intermediate level waste (ILW) packages they are pessimistic, for spent fuel and high level waste (HLW) packages they are optimistic). Thus the results of the calculations are not of great value for supporting the Letter of Compliance (LoC) process, directing R&D or assisting with GDF design.

40. Furthermore, the choice of values of groundwater parameters is not justified by reference to known UK geological environments. It is based on the assumption that the results of the calculations will be most useful if they are below the one in a million per year regulatory guidance level (EA and NIEA, 2009). However, this only becomes clear from reading the lower level gDSSC documents. The failure to mention it in the higher level gDSSC documents gives a misleading impression of the significance of the results of the groundwater risk calculations.

APPROACH TO IDENTIFYING AND FILLING GAPS IN KNOWLEDGE

Current R&D Strategy and Programme

41. RWMD's current R&D Strategy was published in 2009, after considerable consultation. CoRWM considers that the Strategy has proved appropriate for the current stage of RWMD work in the implementation of geological disposal.

42. CoRWM recognises that some of the current RWMD R&D programme was put in place before the Status Reports were written. It would not, therefore, be expected to fill all the generic knowledge gaps identified in the Status Reports. Nevertheless, there is a reasonably good correlation between the topics and priorities in the R&D programme and the knowledge gaps in the reports. The Status Reports will next be updated in 2014, after the current programme of generic gap-filling R&D is complete. By that time it is anticipated more will be known about potential GDF sites and it is expected that new R&D needs will arise as a consequence.

43. Through its attendance at meetings of RWMD's Research Advisory Panel (RAP) as an observer, CoRWM has received information about RWMD's plans to update its current R&D programme document to include new issues and projects. It has also learnt that RWMD is developing an approach to evaluating the success of each R&D project, in terms of the extent to which the project has filled knowledge gaps. CoRWM, whilst noting that the proposals discussed by RAP do not as yet constitute the agreed position of RWMD, considers that such an approach is essential to the successful implementation of RWMD's Technical Strategy.

44. CoRWM commends RWMD for its positive engagement with Learned Societies on R&D issues. It is important that this continues.

Future R&D Strategy and Programme

45. RWMD has told RAP how it intends to revise its R&D Strategy and to develop its next R&D Programme. CoRWM was pleased to learn that RWMD intends to consult extensively on its future R&D Strategy and Programme. Other influences on the future strategy and programme will include the RWMD Issues Management Process and various national and international conferences. CoRWM also understands that RWMD plans to hold further specialist workshops. These are valuable for highlighting changes required to the R&D Programme in the short term and in identifying needs for longer term and site-specific work.

Approach to R&D

46. It is essential that RWMD has the capability to act as an intelligent client for R&D. The gDSSC documents, particularly the Status Reports, show that RWMD does have this capability in many of the relevant topic areas. However, there are a few topic areas for which this is has not been adequately demonstrated to be the case; the principal ones concern the geological barrier (para. 22 *et seq.*) CoRWM emphasises that this does not mean that RWMD may not have this capability, only that it has not demonstrated that it has it *via* the gDSSC documents.

47. CoRWM, whilst recognising that data acquisition forms a critical part of RWMD's R&D programme, notes that it would be unwise to regard future R&D in any of the DSSC topic areas as only having the purpose of acquiring further data. Nor would it be appropriate to regard R&D on any of the topics as merely confirmatory. The role of R&D is also to explore the issues and find out more. For example, in the case of engineered barriers, confirming the stability or predictable degradation of materials over long timescales is important, but it is only one facet of any forward-looking R&D agenda. Similarly, for the geological barrier, R&D may confirm what is already known about radionuclide migration with groundwater or may indicate that hitherto unknown or poorly understood processes are operating.

SITE CHARACTERISATION

48. CoRWM considers that RWMD's site characterisation strategy is developing in an appropriate direction for this stage of the implementation process but is not yet comprehensive. Though predicated on the use of existing proven technologies, it includes decision-making processes that will enable new technologies and methods to be integrated into site characterisation. It is largely sequential, from non-intrusive geophysical investigations to exploratory boreholes and then to underground investigations. However, some iterations between geophysics and exploratory boreholes are likely to be required and CoRWM understands that RWMD is considering this possibility.

49. It is clear that understanding of a site will improve as characterisation progresses. However, better understanding does not necessarily imply reduced uncertainties. For example, improved understanding from surface-based investigations may show that it is not possible to realistically model variations in a key parameter, or to determine groundwater flow paths and predict their evolution. CoRWM suggests that it is made more explicit in future DSSC documents that uncertainties may increase as site characterisation progresses and can even reach the point where a site is judged to be unsuitable, because the uncertainties associated with key variables are too great.

50. The documents state that successful completion of a site characterisation project is marked by the generation of an 'adequate level of understanding' following iterative investigations. An important requirement is to define what is meant by 'adequate level',

how that level of adequacy is recognised, and what process will be put in place to independently review and evaluate this.

51. The Site Characterisation Status Report (report 057) gives the impression that characterisation at the underground investigation stage will be based on the premise that any underground works will be confirmatory. CoRWM understands that RWMD recognises that such a premise is not appropriate and that it did not intend to convey this impression in the report. CoRWM is of the view that a substantial phase of underground site investigation is likely to be required, and hence should be planned for. As with surface-based investigations, it cannot be assumed that more underground characterisation correlates with both increased understanding and decreasing uncertainty. Unsuspected sub-surface heterogeneities or structures may be found, leading to increases in uncertainty and/or questions about site suitability.

CONCLUSIONS

52. CoRWM concludes from its assessment that the gDSSC shows that, in most of the relevant scientific and technical areas, RWMD's understanding of the underpinning knowledge is demonstrated to be sufficiently comprehensive for the current stage of its work. The principal exceptions are in the areas of the characteristics and evolution of geological barriers, and groundwater movement. For these topic areas the gDSSC does not of itself demonstrate sufficient understanding or use of knowledge. However, this is not to say that RWMD may not have enough understanding or the capability to use knowledge of these topics. CoRWM believes that it will be straightforward for RWMD to make any improvements that are necessary before any site-specific DSSC is required.

53. From consideration of RWMD's R&D strategy, programme and implementation processes, and its plans to further develop these, CoRWM concludes that RWMD has, or will have, appropriate processes in place to fill gaps in its knowledge. In the topic areas where it has not yet shown sufficient understanding, it also needs to demonstrate that it has, or will have, the capability to be an intelligent client for R&D.

54. CoRWM concludes that RWMD's site characterisation strategy and plans are not yet comprehensive. They are, however, developing in appropriate directions at this stage of the implementation process, with sufficient provision for taking advantage of new methods and technologies in due course. In communicating its plans for site characterisation, it is important that RWMD does not inadvertently promote unrealistic expectations. While understanding of a site will increase as site characterisation progresses, there may also be increases in uncertainties and these may be large enough to lead to questions about the suitability of the site as a location for a GDF.

REFERENCES

CoRWM Documents

CoRWM doc. 2438. *CoRWM Comments on the UK Radioactive Waste Inventory 2007 and Proposal for an NDA 'Future Scenarios' Publication.* October 2008.

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NDA, 2011a. *Geological Disposal. Review of Options for Accelerating the Implementation of Geological Disposal Programme.* NDA Report No. NDA/RWMD/083. December 2011.

NDA, 2011b. *Geological Disposal of Radioactive Waste: Underpinning Science and Technology.* Proceedings of a Conference held at Loughborough University, 18-20 October 2011.

ANNEX 1 LIST OF GDSSC AND RELATED DOCUMENTS

	Summaries and Main Documents	***RWMD Report No.***
1	An Introduction to the Generic Disposal System Safety Case	-
2	An Overview of the Generic Disposal System Safety Case	010
3	Generic Transport Safety Case – Executive Summary	-
4	Generic Transport Safety Case – Main Report	019
5	Generic Operational Safety Case – Executive Summary	-
6	Generic Operational Safety Case – Main Report	020
7	Generic Environmental Safety Case – Executive Summary	-
8	Generic Environmental Safety Case – Main Report	021
9	An Introduction to the Derived Inventory	-
10	An Introduction to the Disposal System Specification	-
	Assessments	
11	Generic Transport System – Safety Assessment	022
12	Transport Package Safety	023
13	Safety Case Production and Management	024
14	Generic Operational Safety Assessment: Vol.1 Construction and Non-Radiological Safety Assessment	025
15	Generic Operational Safety Assessment: Vol.2 Normal Operation Operator Dose Assessment	026
16	Generic Operational Environmental Safety Assessment	029
17	Generic Post-Closure Safety Assessment	030
	Status Reports	
18	Package Evolution Status Report	031
19	Waste Package Accident Performance Status Report	032
20	Near-Field Evolution Status Report	033
21	Radionuclide Behaviour Status Report	034
22	Geosphere Status Report	035
23	Biosphere Status Report	036
24	Gas Status Report	037
25	Criticality Safety Status Report	038

	Supporting Reports	
26	Generic Disposal System Functional Specification	043
27	Generic Disposal System Technical Specification	044
28	Radioactive Wastes and Assessment of the Disposability of Waste Packages	039
29	Summary of Generic Designs	054
30	Generic Disposal Facility Designs	048
31	Generic Transport System Designs	046
	Other Relevant Reports	
32	Technical Strategy	075
33	R&D Programme Overview	073
34	Site Characterisation Strategy	017
35	Site Characterisation Status Report	057
36	R&D Strategy (2009)	011

Notes

i) All documents were published in 2011 unless otherwise stated.
ii) gDSSC documents are dated December 2010.
iii) Despite its title, the Site Characterisation Status Report does not form part of the gDSSC suite.

ANNEX 2 COMMENTARY ON THE GDSSC

55. This annex contains CoRWM's commentary on the gDSSC and related documents listed in Annex 1. It provides further details of the findings of CoRWM's assessment of these documents and additional comments on them. The commentary is arranged as follows.

DEVELOPMENT AND STRUCTURE OF GDSSC DOCUMENTS

56. CoRWM has been informed by RWMD of the document development, quality assurance and review processes and procedures specifically applied to the gDSSC suite. As these processes are central to its assessment of the gDSSC, the information provided to the Committee is detailed below along with its assessment of it. This is divided into the processes applied to the Status Reports and those applied to the higher-level gDSSC documents as there are logical differences in the requirements for each.

Status Reports

57. RWMD has explained to CoRWM that the Status Reports (reports 031-038) set out to summarise the current state of knowledge and hence to identify R&D needs in each area. The gDSSC goal was to keep these to a target length of 100 pages, irrespective of subject area and knowledge level. It is CoRWM's view that this has a negative effect on some of the Status Reports, which are 'broad brush' rather than being comprehensive and authoritative, and so cannot be said to provide the 'benchmarking' required of the gDSSC. This observation applies in particular to the Geosphere Status Report (report 035). Whilst the intention of being intelligible to a general readership is laudable, it is more important for the purposes of knowledge capture and baseline definition to have a comprehensive, if technical, statement of the status of knowledge in each area.

58. RWMD has informed CoRWM that each Status Report had an RWMD lead author who started out with a specification. This was then checked with the gDSSC team to ensure it met their needs for the safety case. In most cases assistance was required from the supply chain with content, but the RWMD lead authors produced much of the text and therefore retain responsibility for it. Review of draft documents occurred within RWMD, followed by external review, with comments taken on board and audited.

59. The peer review process for the Status Reports was managed through RWMD's Research Advisory Panel (RAP). The reports were sent to a member of RAP and to external reviewer(s) recommended by RAP. The chair of RAP read all the Status Reports. After further revision of the documents by RWMD, the documents plus a reviewers' comments and response log for each document were considered by RAP, which assessed the appropriateness of the response by RWMD to reviewers' comments,. Upon completion of this process the documents were checked by RWMD staff and signed off by the appropriate Head of Department for publication.

60. CoRWM has been informed that all author and reviewer details, and reviewers' comments and changes made in response to them, were recorded as part of RWMD's quality management procedures. However, this information is not openly accessible and hence of use to readers to make judgements about the background and expertise of the authors and reviewers and to evaluate the quality and robustness of procedures underpinning the production of the Status Reports. CoRWM considers that there would have been significant benefits in terms of increased confidence in the gDSSC from providing information on the identities of authors and reviewers and publishing peer reviewers' comments and RWMD responses.

61. There is a distinction between the management of data and peer review of underlying science. CoRWM considers that this should be recognised and borne in mind when developing review processes for future editions of the Status Reports.

62. The key parameters to be used in quantitative safety assessments are recorded in appendices in some Status Reports (*e.g.* for post-closure models), together with reference to the source. CoRWM notes that, although the Radionuclide Behaviour and

Gas Status Reports (reports 034 and 037) have such appendices, as no sensitivity analysis calculations are reported, the importance of the parameters to the safety assessment cannot be judged. In future the presentation of such data needs to be more informative.

Higher Level gDSSC Documents

63. The technical and project management of the gDSSC was undertaken by a project team. The team met at least weekly, coordinating the production of all safety case and status and supporting documents. This was done in parallel, which meant that the team had to be in continuous communication with the various leads on each of the documents for updates.

64. RWMD informed CoRWM that higher level gDSSC documents were checked back against the Status and Supporting Reports to ensure that what was being quoted was correct and that all the documents were consistent. This entailed a great deal of effort because the documents were produced in parallel.

65. An External Advisory Panel provided support for the Environmental Safety Case (ESC) (reports 021, 029, 030) and high level gDSSC Overview (report 010). The panel, which consisted of Professor Neil Chapman (Sheffield University and MCM International), Dr Julie West (British Geological Survey), Professor Andrew Wood (Cambridge), Professor John Murlis (University College, London) and Professor Alan Hooper (Imperial College and acting Chief Scientific Advisor to RWMD), reviewed the documents as 'critical friends'. RWMD conducted an internal review of the ESC and there was early engagement with the regulators.

66. Other internal (RWMD) quality management procedures for the gDSSC included an assurance function independent of the gDSSC team, review of gDSSC documents and of assurance and peer review reports by the RWMD Nuclear Safety and Environment Committee, and sign-off of the Disposal System Functional Specification (report 043) by the Repository Development Management Board (the RWMD Board).

67. Prior to publication, an external peer review of the safety case documents (Transport Safety Case (TSC), Operational Safety Case (OSC) and ESC) was commissioned. To maintain independence, care was taken to avoid any contractors that had been involved in preparation of the documents. Westlakes Consulting was employed to manage the peer review process. Unfortunately the Westlakes business went into administration before the review was completed. The review team was reassembled under the management of David Bennett of TerraSalus. Responses were prepared to the peer review and fed into the final documents. RWMD noted that the design reports were also subject to independent peer review by Atkins.

General Comments on Document Review Processes

68. CoRWM considers that the review processes for the gDSSC documents were effective in evaluating what had been done in the given context. However, they did not assess whether the work could have been done in better ways. They were constrained to be assessments as to whether the goals were achieved, and so were reflective of the framework in which those goals were set.

69. External reviews of most gDSSC documents were carried out at a fairly late stage in drafting, when it was difficult for RWMD to make major changes or to carry out additional work such as post-closure risk calculations and sensitivity analyses. CoRWM suggests that, for future DSSCs, RWMD considers involving external experts at an earlier stage, so that there can be more independent input.

70. It is important to distinguish internal quality assurance processes from independent peer reviews. In some of the material it presented to CoRWM, RWMD seemed to mix the two.

71. It would be preferable if future DSSC documents clearly described the assessment and review processes used. This would, in CoRWM's view, enhance confidence in RWMD's safety cases.

Relationships between gDSSC Documents and Technical Strategy

72. The Technical Strategy (report 075) sets out to communicate to stakeholders and the public "what RWMD is all about". It is proposed to update the Technical Strategy about every 3 years. At the outset it summarises the hierarchy of key documents. One of the main functions of the Technical Strategy is to identify key products that need to be delivered. There is significant uncertainty about some aspects of implementation of the strategy, particularly on issues like sites and the timing of steps.

73. CoRWM considers that the 16 'strategic activities' identified in the Technical Strategy are all appropriate. It notes that 13 of these directly relate to the gDSSC.

74. Report 075 states that RWMD's technical development is based on a knowledge platform of science, technology and engineering. CoRWM notes that the documents that record this technical basis are effectively the gDSSC suite and its supporting reports.

75. The overall process for delivery of the Technical Strategy is clearly described in terms of the component planning parts (framework, drivers, develop programme, implement and evaluate). However, these in themselves only constitute a template for activity. They do not convey how the strategy translates into the work covered in the gDSSC. When the gDSSC itself is examined, there is little 'back linkage' to the strategy process template in the Technical Strategy (report 075). It would have been beneficial to incorporate a case study (worked example) of how the strategic process has been applied to a specific need identified within the gDSSC.

76. The Technical Strategy indicates that RWMD uses seven 'structured questions' in developing its technical programme of work. The questions are all relevant and appropriate, as are the additional considerations regarding timing. However, no information is given as to how the questions are addressed, nor about the roles played by the various advisory panels and committees in addressing the questions.

77. The section in report 075 on 'Delivery of the Technical Strategy" is central to how RWMD develops its gDSSC. The information provided is largely programmatic and (with the exception of the section on peer review) says very little that gives an understanding of how the gDSSC has been formulated within the strategy and how the defined strategic activities are actually delivered.

Environmental Safety Case

78. Since the gDSSC documents were published, RWMD has given consideration to how an ESC will be developed for a GDF at a specific site. In August 2011 it issued an 'ESC Strategy' to regulators, which sets out the stages of development towards a site-specific ESC. Similar forward strategy documents will be prepared at a later date for the OSC and TSC.

79. RWMD has told CoRWM that the generic ESC will not evolve into a site-specific ESC. Rather, a site-specific ESC will be developed in parallel with maintaining the generic ESC.

80. The rationale for this approach is that there will be a continuing need for the gDSSC suite, for purposes such as further development of Waste Package Specifications and disposability assessments under the Letter of Compliance process. The gDSSC will therefore be maintained as a live set of documents representing RWMD's knowledge base, and will be periodically updated as required.

81. CoRWM understands that the ESC strategy document shows the "mapping" between: (i) the MRWS process; (ii) the generic ESC; (iii) iterative development of a site-specific ESC and (iv) key safety case submissions. RWMD also has a plan as to how post-closure models are expected to evolve as they move from generic through to the site-specific ESC.

UNDERSTANDING AND USE OF KNOWLEDGE IN ASSESSING AND DEMONSTRATING POST-CLOSURE SAFETY

Characteristics and Behaviour of the Geological Barrier

82. This section of the annex contains comments on the Geosphere Status Report (report 035) and geological aspects of the higher level gDSSC reports.

Terminology

83. It should be noted at the outset that CoRWM uses the term "geological barrier", rather than the term "geosphere", when referring to the geological domain surrounding a GDF. This is because "geosphere" has a different meaning in the Earth Sciences and CoRWM considers that the term has been misappropriated both in RWMD's gDSSC and in the literature of some radioactive waste management organisations (WMOs) in other countries. CoRWM notes that the US Presidential Blue Ribbon Commission refers to "geological barrier", rather than geosphere. CoRWM considers that RWMD should do the same. Clear and consistent use of terminology is very important in communications about geological disposal.

Overall View on Understanding of the Geological Barrier

84. CoRWM's overall view is that the gDSSC gives the impression that RWMD does not know as much about the geological barrier as would be expected at this stage in the implementation of geological disposal in the UK. This is a result of a number of aspects of RWMD's approach to the gDSSC.

85. CoRWM considers that the adoption of the very broad rock-type categorisation of 'higher strength', 'lower strength sedimentary' and 'evaporites' compromises the ability of the gDSSC to convey sufficient understanding of the geological barrier and the importance, in particular, of heterogeneity and structure. More specifically, the 'Higher Strength Rocks' category groups together rocks with very different scales and geometries of heterogeneity (*e.g.* granites, gneisses, lavas, volcaniclastics and indurated sedimentary rocks). No justification is given for including 'older sediments' in this category. Grouping these in with igneous intrusives and metamorphic rocks suggests an inadequacy in understanding the differences in the types and scales of heterogeneity in the various rock types. In the case of Lower Strength Rocks, the figures and text give an oversimplified perspective of sediments in general. It would be preferable to add material on sedimentary architecture and lateral changes in sedimentary facies, and to acknowledge the importance of understanding basin subsidence and evolution.

86. CoRWM recognises the difficulties in providing a generic description of the geological barrier and its functions but considers that the three category approach is far from ideal. It would probably have been better to provide a suite of specific examples, rather than

trying to fit all potential host rocks into three categories. This would have demonstrated more effectively that RWMD understands thoroughly the possible range of characteristics and behaviour of the geological barrier. It would also have shown that RWMD understands how the safety contributions of the geological and the engineered barriers vary with time after GDF closure in various types of host rocks.

87. The Geosphere Status Report (report 035) does not provide adequate coverage of the geological and hydrogeological knowledge required for a DSSC. One example of where material has been omitted is the sections on THMC perturbations induced by a GDF, which simply describe the nature and potential sources of some of these perturbations. Little indication is given as to how they can or would be assessed quantitatively; what measurement, modelling and predictive techniques are available; or how much confidence can be placed in the results. It is surprising that this type of information is not provided, given the involvement of RWMD in such international research projects as DECOVALEX.

88. CoRWM considers that it was unwise to attempt to cover all the geological and hydrogeological knowledge needed in one status report. The Committee suggests that in future it would be better to prepare at least two reports on these subjects, for example one on geology and one on hydrogeology.

Seismicity

89. Earthquake magnitude is not the only parameter of importance when considering possible impacts of seismicity. Depth to focus is also a factor in damage because of the difference in relative importance of surface waves *versus* body waves (both pressure and shear (transverse) waves). CoRWM notes that the seismicity map provided does not convey information on a scale commensurate with that required for characterisation of the geological barrier for the purposes of siting.

90. The greatest impact of any seismicity in the UK is likely to be on bulk rock permeability. Across-fault flow determinations, though of value in 3-D characterisation and understanding, are not relevant to estimating the potential effect of future seismic activity on along-fault flow from the depth of a GDF to the shallow subsurface. Evidence from oil fields shows that hydrocarbons can migrate episodically along faults and that some faults can act as ‘pipes’ through which fluids can move rapidly.

91. The gDSSC consideration of seismicity would have been improved by coverage of permeability evolution due to shallow micro-seismic events (*i.e.* magnitude <0, 1, 2 on the logarithmic scale). Shallow micro-seismic events can be caused by tidal fluctuations, GDF construction, hydraulic head changes, glaciation *etc.* They can increase the permeability of the fractures on which they are hosted over a rupture patch area that is related to the event magnitude.

Fractures

92. Much is made in the gDSSC reports of the potential for radionuclide sorption onto minerals on fracture surfaces, such as clays and iron (oxy)hydroxides. However, among the commonest minerals lining fractures, especially open fractures, in typical “higher strength” rocks are quartz and calcite. The sorption of radionuclides onto these minerals should have been described and quantified.

93. There is a suggestion in the Geosphere Status Report (report 035) that a GDF could be constructed to avoid intersecting highly fractured zones of increased groundwater flow (*e.g.* faults). This is desirable as it would increase the isolation of the waste from potentially rapid return paths to the surface. However, if several hundred metres is

deemed the necessary vertical isolation, a similar lateral distance would need to be maintained from any fault zone. This has implications for the overall size and design of any GDF sited in faulted host rocks.

Oxidised and Alkaline Disturbed Zones

94. The work on the oxidised zone and the alkaline disturbed zone in clay rocks is described well, and is underpinned by comprehensive studies in those rock-types by other WMOs. By comparison, the description of the status of work on these zones for higher strength rocks is superficial. In particular there is no quantitative information on the length scales of these zones in such rocks. CoRWM recognises that it is difficult to be categorical because of heterogeneity, but quantification of these scales (even conservative minimum-maximum envelopes) would have been of benefit in demonstrating understanding of the work that would be required for a site-specific safety case for a GDF in higher strength rock.

Characteristics and Behaviour of the Engineered Barriers

95. In CoRWM's view, the gDSSC shows that RWMD has a good understanding of the possible characteristics and behaviours of engineered barriers. The Status Report on Near-field Evolution (report 33), for example, gives good coverage of issues associated with the role of the near field and safety functions that may be provided by the engineered barrier systems (EBS). The sections on future R&D needs are particularly useful because they show the high level drivers (DSSC, development of GDF concepts *etc.*) and the overarching near-field evolution research topics.

96. CoRWM notes that it is important not to give the impression that RWMD regards all R&D on engineered barriers as confirmatory. The role of R&D should also be to explore the issues and find out more so that the concept of 'good enough' is well-founded. Confirming the stability or predictable degradation of materials over long timescales is important, but it is only one aspect of the required R&D agenda.

97. CoRWM also notes that a high level of reliance on EBS performance will require strong evidence to support it, particularly about the quality of EBS manufacture and emplacement, and about the long-term behaviour of materials. For example, extrapolation of empirical data obtained by observing waste packages over decades to the timescales of thousands of years, or tens or hundreds of thousands of years that may be a requirement for EBS performance requires fundamental understanding of corrosion mechanisms. Care is also required not to over-emphasise the significance of analogues such as the cement in Hadrian's Wall. (Hadrian's Wall does not contain radioactive waste, is not underground in reducing conditions, and the cement is a completely different formulation to that used to encapsulate UK ILW.)

98. It would have been preferable to have given more consideration to the interaction of container corrosion products with wasteforms and near-field EBS materials, and the consequent impacts on durability and radionuclide release rates. There is also very little consideration in the gDSSC of how the evolution of the geological barrier (*e.g.* stress distribution changes, extents of and changes in fluid buffering) may impact on package performance.

99. Other factors that may need to be considered in future DSSCs are:
    - a range of rock types may need to be traversed by drilling in order to access suitable rock and rock volume for a GDF, leading to requirements for backfilling materials with differing properties;

- it may be necessary to demonstrate that there will be no adverse post-closure interactions between the near-field environments of differing waste types (*e.g.* HLW and ILW);
- the implications of package evolution on timescales for retrievability.

Groundwater Pathway

Groundwater Movement

100. Groundwater movement is another subject on which too little information is given in the gDSSC documents, particularly the Geosphere Status Report (report 035). This does not cover in enough detail the topic of how to gain an understanding of present patterns and rates of groundwater movement at a prospective GDF site. Nor does it cover adequately how RWMD would predict future patterns and rates of groundwater movement at a specific site in response to natural processes (*e.g.* climate change) or GDF-induced perturbations (*e.g.* the heat output of wastes).

101. There is only one section of the Geosphere Status Report (report 035) that deals with the complex topic of using site characterisation data to set up and validate a conceptual and a numerical model of present groundwater movement at a site. This section is only five pages long and consists almost entirely of examples from other countries, with a few references to UK work. It shows that the capability to carry out such modelling exists in other organisations. CoRWM considers that what was needed in the gDSSC was a demonstration that the capability exists in RWMD or that RWMD is able to act as an intelligent customer for such modelling.

102. There is little explanation of how the two basic types of groundwater flow model (discrete fracture network (DFN) and continuous porous medium (CPM)) are linked. There is only a reproduction of what appears to be an illustration from another document. Furthermore, the challenge of characterising the high degree of heterogeneity that can occur in fractured rocks and developing groundwater flow and transport models that are representative at local and regional scales is not addressed. In many cases, sparse network models are far more appropriate for modelling groundwater flow at both the local and the regional scales.

103. There is no explanation in the Geosphere Status Report (report 035) or the post-closure safety assessment (report 030) of how, for future safety cases, the results from complex numerical models of groundwater movement will be used to support the assumptions and derive the parameters used in the simple models used for calculations of radiological risks *via* the groundwater pathway. At the very least, CoRWM would have expected examples to be given of how this has been done in other post-closure safety assessments of geological or near-surface disposal facilities, either in the UK or other countries.

Radionuclide Behaviour in Groundwater

104. The Status Report on radionuclide behaviour (report 034) covers processes that affect how radionuclides enter groundwater, are transported in groundwater and are re-deposited onto or into solids (engineered barrier materials and materials in the geological barrier). The processes discussed are:

Processes affecting radionuclide release from wasteforms;
  - wasteform dissolution or leaching
  - solubility limitation

Processes affecting radionuclide transport;
  - advection and hydrodynamic dispersion
  - diffusion
  - transport by colloids, non-aqueous phase liquids (NAPLs) and microbes

Processes affecting radionuclide retardation and immobilisation;

- sorption
- complexation
- precipitation / co-precipitation
- molecular filtration and ion exclusion
- rock-matrix diffusion
- microbial activity
- NAPLs.

105. This is a complex area of science, underpinned by a huge body of literature, and its distillation into the Status Report must have been a substantial undertaking. The authors are to be congratulated for producing a well written, coherent document that fulfils well its purpose of providing a comprehensible review of the state of the art. The Status Report shows that RWMD has a good understanding of the processes involved in radionuclide behaviour and how they can be modelled.

106. CoRWM agrees that several issues are best left for site-specific investigation; these include many aspects of transport by colloids, and microbial effects. In the meantime, RWMD is funding R&D on, *inter alia,* radionuclide release from vitrified HLW and spent fuels, the impact of NAPLs on radionuclide behaviour, and some generic aspects of colloids. It is also funding the development and maintenance of an internally consistent database[3], and is contributing to an NEA project to produce internationally agreed datasets. This approach to generic R&D seems sensible.

107. The Status Report also describes how radionuclide behaviour is currently represented in RWMD's assessment models. This involves a considerable number of simplifications. It is unclear to CoRWM whether, taken together, these simplifications will tend to overestimate or underestimate post-closure radiological risks. On some topics, RWMD appears to be making simplifications that are pessimistic (*e.g.* on radionuclide chemistry) but there are also statements that appear optimistic (*e.g.* on colloids). It is important to be consistent. In CoRWM's view it is better to aim for realism, and deal with uncertainties *via* probabilistic calculations, than to use an approach that involves varying degrees of caution.

Gas Generation and Migration

108. The discussion below is based on the status report on gas (report 037) and the gas sections of the main report on the environmental safety case (report 021) and the report on the post-closure safety assessment (report 030).

109. CoRWM's overall view is that the treatment of gas generation and migration in the gDSSC suite of documents is reasonably comprehensive and reflects the current state of knowledge. CoRWM agrees with the conclusion that continued detailed gas modelling for any particular rock type would not be a good use of resources in the near future, and that more attention should be paid to gas issues that affect site assessment and characterisation.

Principal Issues

110. The two principal issues related to gas generation and migration are:
    - whether the production of bulk gases could lead to a pressure build up and hence alter groundwater flow in and around a GDF or have other disruptive effects;

[3] J.E. Cross and F.T. Ewart,: HATCHES - A Thermodynamic Database and Management System Reprint Radiochimica Acta 52/53, pp. 421-422 (1991)
ZZ HATCHES-19: T. G. Heath: The HATCHES User Manual, February 2011

- the potential health risks to people and other organisms from release of radioactive gases to the biosphere.

111. The three gases of concern arising from corrosion of metals (both metallic wastes and waste containers), radiolysis of water and organic materials, and microbial degradation of organic materials are hydrogen, carbon dioxide and methane. They can migrate as free gases or dissolved in groundwater. Migration of some gases can be retarded by chemical interactions with engineered barrier materials (*e.g.* carbon dioxide interacts with the cementitious materials likely to be used for backfilling).

Bulk Gases

112. Corrosion of metals is the main process that can generate bulk gases. Most of the gas produced will be hydrogen but there will also be small amounts of carbon dioxide and methane.

113. The gDSSC position is that bulk gas generation is an important issue for GDF design and post-closure safety but one that is at least rock-type specific and probably site specific. From the qualitative arguments presented' it appears that bulk gas production is not a "show-stopper" for any rock type in which a UK GDF might be located. There is no reason to doubt this conclusion but CoRWM notes that it is not backed up by calculations included in the gDSSC documents or by references to GDF safety cases in other countries.

114. The gDSSC documents tend to treat generation of bulk gases separately from their migration. This can lead to overestimation of the importance of bulk gases. For metals to corrode, water must be present. If gas pressure is to build up substantially, there must be no major existing escape route for the gas (*e.g.* a large water-bearing fracture) and no gradual dissipation of the gas (*e.g.* through small fractures created by initial pressure rises). Modelling gas generation and migration separately, without considering how likely it is that conditions for both will occur together, can lead to unrealistic results and is too simplistic an approach for future GDF post-closure safety cases. This is implicitly recognised in the qualitative discussion of gas in the post-closure safety assessment (report 030) but is not given sufficient prominence elsewhere in the gDSSC documents.

115. A further source of overestimation of the importance of bulk gases is the neglect of gas consumption processes. Data presented in one of the references[4] in the Gas Status Report suggest that microbial consumption of hydrogen could be significant. The hydrogen would be a nutrient for microbes in a GDF that are adapted to anaerobic conditions, stimulating their growth and thus increasing gas consumption. In the gDSSC it seems to be assumed that most microbes in a GDF would be adapted to aerobic conditions. While this may be the case before closure, the relative abundances of aerobic and anaerobic micro-organisms at long times after closure at prospective UK GDF sites cannot be predicted.

Radioactive Gases

116. The DSSC position on radioactive gases is that only methane containing carbon-14 ($^{14}CH_4$) could present a significant risk. It is argued that carbon dioxide containing carbon-14 would be retained in a GDF because of carbonation in the cementitious backfill. There are no calculations in the gDSSC documents to support these conclusions.

[4] Small, J, *et al.*, Experimental and modelling investigations of the biogeochemistry of gas production from low and intermediate level wastes. Applied Geochemistry **23**, 1383-1418, 2008.

117. It is unclear to CoRWM whether $^{14}CH_4$ will present significant risks. It appears that the main generation route for the gas is corrosion of metals (especially steels containing carbon-14) but there is no quantification in the gDSSC documents of possible generation rates and there is mention of "cautious assumptions". $^{14}CH_4$ generation from graphite is mentioned in the Gas Status Report, but not in the post-closure safety assessment, and the impression given is that it is insignificant.

118. It is clearly essential to investigate the potential rates of generation of $^{14}CH_4$, to determine whether current assumptions are conservative and if so by how much. CoRWM understands that RWMD has such R&D in hand and that it covers generation of $^{14}CH_4$ from metal corrosion and from graphite. In the Committee's view, this R&D has higher priority than that on the behaviour of $^{14}CH_4$ in soils, which RWMD is also funding. CoRWM notes that there may also be a need for further R&D on carbonation.

Criticality

119. The Criticality Status Report (report 038) is a well written, coherent document which fulfils well its purpose of providing a comprehensible review of the state of the art. CoRWM has confidence that RWMD is an intelligent client in this area, and is able to utilise contractors' work effectively and with considered judgement.

120. Work has focused on ILW and spent LWR fuel (the latter being based largely on work by WMOs in other countries). Only very limited consideration is given to the impact of disposals of AGR spent fuel, plutonium or uranium on criticality, although these are included in the baseline inventory. With respect to LWR fuels, reference is made to the safety studies done in the programmes of Belgium, Sweden and the United States.

121. US work is cited to support the gDSSC conclusion that there are well-established, validated routes for determining the combination of parameters that would give rise to a critical system. Analyses by Serco to determine the parameters for critical configurations of plutonium and uranium in oxide form are used to argue that the concentrations of fissile material in ILW and HLW would have to increase by three orders of magnitude before a critical mass could form. The report clearly acknowledges that the ability for fissile material to accumulate depends on package longevity.

122. It is apparent that RWMD has relied heavily on Galson Sciences and Serco. Examples of the Serco work relied on include the following:
- Two 'what if' scenarios based on stack slumping and slow accumulation have been assessed by Serco as part of the Understanding Criticality under Repository Conditions (UCuRC) programme.
- Work by Serco (2009) is referenced as showing that the computer models have undergone thorough verification and some benchmarking has been performed.
- The natural criticality event at Oklo is given as a source of data for validation and the Serco report of 2009 is referenced for validation.
- A Serco (2008) report is cited to show that for ILW a criticality event would increase the dose via the groundwater pathway by a factor of 2 but not affect the peak from the gas pathway, as that peak is predicted to occur before the criticality event could take place.

Characteristics and Evolution of the Biosphere

123. The Biosphere Status Report (report 036) deals not with all aspects of the biosphere but only with the surface biosphere that acts as a "receptor" for radionuclides travelling through the geological barrier with groundwater or gas from the GDF. Biological aspects of the behaviour of engineered barriers and the geological barrier are covered in other

status reports (*e.g.* the Gas Status Report for effects of microbial activity on gas generation and the possible consumption of gas by microbes).

124. The RWMD approach to the biosphere described in report 036 is the conventional one that is used by WMOs in GDF post-closure safety assessments. This is based on defining reference biospheres linked to assumed climatic conditions and calculating radiation doses to notional reference people and other notional reference organisms. The approach has been agreed internationally and is well-suited to demonstrating compliance with the numerical standards in the environment agencies' Guidance on Requirements for Authorisation (GRA) document (EA and NIEA, 2009). In it, all the biosphere calculations are merely means of putting releases from the geological barrier into perspective.

125. CoRWM notes that the Biosphere Status Report (report 036) does not provide sufficient explanation of the background to and rationale for this conventional, internationally agreed approach. Nor does it indicate that RWMD is aware of the limitations of its approach or of work in progress that could necessitate changing or supplementing it in future. In particular, CoRWM suggests that, given the current emphasis on ecosystem services in international, European and domestic policy, RWMD will need to provide more evidence that it understands how ecosystems function, not least because of the implications of climate change for environmental conditions in the future.

126. CoRWM also considers that it is important to recognise in a GDF safety case that geosphere (in the correct sense) and biosphere are not discrete items but show considerable overlap. Whether the interest is in predicting what the biosphere might look like in the future or in assessing the radionuclide impact on its components, it is essential to pay sufficient attention to micro-organisms. These provide a conceptual link between geosphere and biosphere and are very likely to evolve in response to significant changes in radionuclide concentrations and radiation fields in their near environment. These organisms are fundamental to the structure and maintenance of soils upon which terrestrial ecosystems depend.

Calculations of Post-Closure Radiation Doses and Risks to People

127. The post-closure safety assessment (report 030) contains calculations of post-closure risks *via* the groundwater pathway and calculations of doses to inadvertent intruders. There are no calculations of doses or risks *via* the gas pathway.

Purpose and Scope of Groundwater Risk Calculations

128. The groundwater risk calculations are described as “stylised”. Their stated purposes include informing the disposability assessments carried out by RWMD for proposed waste packages, focusing R&D and providing an input to GDF design.

129. The calculations consist of a reference case and a sensitivity analysis. They are all “probabilistic”, in the sense that they use probability distributions of many parameters, not single values.

130. The geological setting considered in the calculations is entirely notional and is only described in terms of a few properties of the rocks. The host rock is taken to be “higher strength”, with reducing groundwater. The overlying rock has oxidising groundwater and is apparently similar to a sandstone.

131. The calculations are for the baseline inventory. There is a brief discussion of how the results would change if the upper inventory was used.

Modelling Approach for Groundwater Risk Calculations

132. The modelling approach in the gDSSC is essentially the same as that used by Nirex in its generic post-closure assessments of 2001 and 2003. This, in turn, is similar to the approach used for the Nirex 1995 and 1997 assessments.

133. The approach is different in a number of respects compared to those used in recent UK assessments of the post-closure safety of near-surface disposal facilities and some assessments for GDFs in other countries. In particular, the approach is based on geosphere and biosphere conditions that do not change with time, so no account is taken of potential climate changes over the million-year period modelled in the calculations. Thus the gDSSC does not demonstrate that RWMD has up-to-date tools to carry out the site-specific groundwater risk calculations required for future safety cases.

134. The modelling approach used to calculate rates of radionuclide release into groundwater is too simple to be able to be realistic. For example, no account is taken of the potential failure of a fraction of HLW and spent fuel containers at very early times, owing to manufacturing defects or for other reasons. Instead a single distribution of container lifetimes is assumed, with a peak of half a million years, which is optimistic. In contrast, no account is taken of the physical properties of graphite wastes, which will tend to resist penetration by groundwater. Instead, it is assumed that all of the graphite waste is in contact with groundwater, which is pessimistic.

135. The values for radionuclide-dependent parameters are justified in detail in the Status Report on radionuclide behaviour (report 034) and it is clear how they relate to possible UK sites and GDF designs. In contrast, little justification is given for the values chosen for the high-level groundwater parameters (specific discharge, travel time, mixing flux, discharge area). It is therefore difficult to relate the results to the conditions that might be found at prospective GDF sites in the UK. CoRWM notes that this led EA to question whether the results of the calculations could be used to inform the MRWS siting process (EA and ONR, 2011).

Results of Groundwater Risk Calculations

136. The results of the reference case calculations provide no new insights into the wastes or radionuclides that could contribute most to post-closure risks. In particular, it is not surprising that depleted, natural and low enriched uranium (DNLEU) dominates. All post-closure safety assessments for GDFs show that uranium-238 and its daughter products make major contributions to calculated risks if there are substantial quantities of uranium-238 present in the wastes. There is about 2TBq uranium-238 in the baseline inventory, of which about 95% is in the DNLEU.

137. The sensitivity analysis is limited, both in terms of the number of parameters that are varied and because of the approach of varying one parameter at a time. It is difficult to see how the results will assist RWMD in future disposability assessments (including those for LoC purposes), focusing R&D or GDF design, other than by providing some further documented results for waste types not considered in the Nirex 2001 and 2003 generic assessments for ILW. CoRWM notes that EA, in its review of the ESC, also questioned the value of the post-closure risk calculations for these purposes (EA and ONR, 2011).

Intrusion Dose Calculations

138. The calculations presented are of doses to a geotechnical worker who examines waste samples brought to the surface following drilling into a GDF when records of its existence

have been lost. This is a standard inadvertent intrusion scenario that is considered in most post-closure safety assessments of GDFs. Not surprisingly, some of the calculated doses are very high (of the order of 10Sv for waste types such as PWR fuel).

139. While it was worthwhile to include them, the intrusion dose calculations add little to what is known from other post-closure safety assessments.

PRE-CLOSURE SAFETY ASPECTS

Construction and Operation of a GDF

140. Very little is said in the gDSSC about construction of the surface facilities, access adit and shafts and first disposal vaults. To demonstrate its intelligent client capability, it would have been helpful to say more about how RWMD will comply with the general requirements for construction of nuclear facilities in the SAPs (HSE, 2008). CoRWM notes that the influence of construction methods on post-closure safety will need to be dealt with in detail in site-specific DSSCs.

141. The issues related to construction of further vaults and tunnels in parallel with waste emplacement are examined only superficially. This is a fundamental feature of a GDF that deserves considerable attention in a DSSC. For example, it could lead to various scenarios in which construction impinges on operation or *vice versa*. There could also be events during construction and operation that could affect post-closure safety. CoRWM notes that ONR, in its review of the OSC, comments that RWMD will need to assess carefully various aspects of parallel construction and waste emplacement (EA and ONR, 2011).

142. With respect to operation, there is much emphasis in the gDSSC on package performance and little on other requirements in SAPs and REPs. The intention is that packages that are made to generic specifications that ensure their performance under all foreseeable operational conditions will be satisfactory. CoRWM considers that the issue for a site-specific OSC is thus one of quality assurance, *i.e.* whether packages meet the appropriate specifications, not one of predicting performance. However, the generic specifications are not closely linked to post-closure conditions and a site-specific ESC will need to contain detailed modelling of package performance post-closure.

143. Another fundamental feature of a GDF is that part of it is underground. Most aspects of this feature are dealt with in reasonable detail in the gDSSC (*e.g.* ventilation arrangements, emergency procedures). The issues surrounding emergency procedures are likely to require further consideration in development of the DSSC.

Transport of Waste Packages to a GDF

144. Much of the material on transport in the gDSSC is about compliance with regulations, which is largely a matter for waste producers (the consignors), not RWMD (the consignee). It would have been helpful to make clearer where RWMD's work will end and waste producers' work will start. In particular, there could be a statement on whether RWMD's package development work will cease once it has finished its work on standard waste transport containers (SWTCs).

145. CoRWM notes that the Disposal System Technical Specification is more informative about transport infrastructure requirements than the TSC report (report 019). It considers that the TSC report does not recognise sufficiently the large scale of transport operations that will be needed for a GDF compared to current transport operations for fuel and LLW. In addition, more might have been said about the effects of disruption to the transport network (*e.g*. as a result of adverse weather conditions). There could also have been

something on expected numbers of incidents and accidents per year when a GDF is operational. CoRWM notes that ONR commented that there is a need for RWMD to refocus its TSC on logistics and infrastructure, and on strategic issues, rather than dealing with compliance with transport regulations (EA and ONR, 2011).

Accident Performance of Waste Packages

146. The Waste Package Accident Performance Status Report (report 032) describes RWMD's knowledge in the areas that determine the release of radioactivity following an accident that involves an impact or a fire or both simultaneously. The scope of the report includes packages for spent fuels, HLW and ILW/LLW during transport and operations in a GDF prior to backfilling. It does not cover DNLEU, highly enriched uranium (HEU) or plutonium.

147. The report demonstrates a good knowledge of the relevant subjects. It shows that a considerable amount of experimental work and work to develop finite element analysis for impact and fire accidents has been carried out for grouted waste in standard Nirex waste packages. However, it also shows that there is a need to carry out work on waste forms and packages that were not considered by Nirex, aged packages (*i.e.* packages that have been stored for many years prior to disposal), transport containers, accidents that combine impact and fire, the effects of underground rock falls and tunnel collapses onto packages, and the effects of flooding. Relatively little work has apparently been done on disposal canisters and there is surprisingly limited reference to work carried out overseas.

148. Conceptual designs are presented for disposal canister transport containers for spent fuels and HLW (DCTCs) and unshielded ILW (UILW) packages (SWTCs). However, no work on the International Atomic Energy Agency (IAEA) mechanical, thermal and immersion tests is described, though RWMD is noted as doing work to understand the performance of these packages.

149. Discussion on the effect of dropping a spent fuel or HLW disposal canister is limited to a report produced by Posiva, which focused on copper spent fuel containers and so may not be entirely appropriate to UK spent fuel containers if those differ in the metal used, design, and fabrication. There is little discussion of work done in other countries or of the extent to which finite element modelling has been validated for disposal canisters.

150. Discussion of the effect of a fire on a spent fuel/HLW disposal canister also refers to a report produced by Posiva, but again there is no description of work done in other countries. A one-dimensional finite element analysis has been done for a copper canister but the extent to which the methodology has been validated for this case is not discussed. Only qualitative arguments as to why the consequences would be negligible are presented.

151. The extensive experimental work that was carried out by Nirex on the effect of impacts on the standard Nirex ILW packages is summarised. However, that work did not explicitly consider the effect of aging of containers or their contents.

152. There is an extensive database and capability for grouted waste in standard Nirex containers. The extent to which the validation of this methodology is applicable to other waste forms and containers is not discussed but the report acknowledges that full scale tests may be required.

153. With respect to the effects of fire, the report summarises the range of full scale tests that were carried out on cementitious waste in 500 litre drums. The claim is made that

these tests provide sufficient understanding of performance and no further full scale tests are necessary.

154. Also summarised is the finite element methodology that was developed by AEA Technology to evaluate the effect of fire on cementitious waste packages and the small scale active furnace tests on actual and simulated waste that were carried out for Nirex. How uncertainties are treated and the range of conditions for which the methodology has been validated are not discussed.

155. The section on further work addresses each of the relevant topics but it does not assign the level of knowledge gap, impact or priority that is contained in the R&D overview report (report 073).

GDF SPECIFICATIONS AND DESIGN

Inventory

156. The gDSSC is based on a Derived Inventory that is itself based on the Baseline Inventory set out in the 2008 White Paper (Defra *et al.*, 2008) (and in turn based upon the 2007 UK Radioactive Waste Inventory). There is also some consideration of an Upper Inventory.

157. The approach is incorporated in the Disposal System Functional Specification (report 043) and the Disposal System Technical Specification (report 044). These Specifications state that “design and development of the disposal system shall be based on the Baseline Inventory”, with a variant transport system and variant GDF designs to “accommodate the Upper Inventory”.

158. This approach is not unreasonable for the gDSSC but CoRWM considers that it is not appropriate for future GDF siting studies, site-specific disposal system design and development, or for taking account of inventory uncertainties in the post-closure safety case. RWMD’s task is to implement geological disposal for all the wastes, spent fuels and materials for which such disposal is the chosen long-term management option. Its approach to this task should be to achieve the combination (or combinations) of GDF site, design and inventory that best meets the overall objective. Thus, as a matter of principle, it is desirable that the Functional or Technical Specification for a GDF is not based on a single, fixed inventory.

159. On a more practical level, neither the Baseline Inventory nor the Upper Inventory are now realistic in the sense of representing current or likely future UK strategy for the management of HAW, spent fuels and nuclear materials. The Baseline Inventory contains plutonium, most of which is unlikely to be declared a waste, but does not contain new build spent fuels, which are. The Upper Inventory is also unrealistic in a number of respects (*e.g.* quantity of new build spent fuel, the assumption that all AGR fuel is reprocessed).

160. For siting, design and development, RWMD should use a scenario approach, as CoRWM recommended in 2008 (CoRWM doc. 2438) and in its 2009 report to Government on geological disposal (CoRWM doc. 2550). A scenario approach is essential because the inventory has such a strong influence on the size, design and siting of a GDF. Ideally, the UK should be looking for a large enough volume of suitable geology to take the whole inventory for disposal in one GDF, even though the final inventory may not actually be known until waste emplacement ends. Realistically, however, it may not be possible to find a large enough volume of rock, particularly if new

build wastes and especially spent fuels have to be accommodated for a protracted generation programme, so greatly enlarging the GDF.

161. The most appropriate approach may be to consider three inventories in siting and design: a best guess, a realistic minimum and a realistic maximum. There is also merit in taking a modular approach to design, in which a particular part of a GDF is tailored to a particular type of waste. CoRWM understands that RWMD is considering using such a modular approach.

162. CoRWM notes that, since the gDSSC was completed, DECC and NDA have published the 2010 estimate of the quantities of waste for geological disposal (DECC and NDA, 2011). This considers a 16GW programme of new nuclear power station construction, as well as the 10GW programme assumed in the Upper Inventory. The Committee also notes that RWMD has published a report that updates its disposability assessments for new build ILW and spent fuel in the light of the gDSSC (NDA-RWMD, 2011). This considers 10GW and 16 GW programmes.

163. It is important to recognise that there are several sorts of inventory uncertainties. One is about which types of wastes will be placed in a GDF. Others are about the quantities and characteristics of those wastes (*e.g*. packaged volumes, radionuclide content). The gDSSC does not deal adequately with uncertainties about waste types to be placed in a GDF and does not deal at all with uncertainties about the quantities and characteristics of each waste type.

164. A scenario approach would address uncertainties about types of waste and quantities of particular types. Sensitivity analyses could be used to address uncertainties about waste characteristics, such as amounts and concentrations of key radionuclides. CoRWM notes that EA and ONR recommend that RWMD includes a wider exploration of inventory uncertainty, including types, volumes and characteristics of wastes, in future DSSCs (EA and ONR, 2011).

Design of Underground Facilities

165. CoRWM welcomes the consideration of six illustrative concepts (one each for ILW/LLW and HLW/spent fuel in three generic geological environments) rather than two reference ones in one rock type. However, the Committee notes that the illustrative concepts do not span the range of possibilities (*e.g*. for depth, for location of surface facilities in relation to underground facilities).

166. Although a multi-level GDF is mentioned (in report 048) as a possibility, most attention is paid to designs in which vaults and tunnels are on a single level. CoRWM notes that RWMD work since the publication of the gDSSC has considered several multi-level concepts (NDA, 2011a).

167. There is no mention of the potential post-closure interaction of near-field environments from various parts of a GDF containing different wastes (*e.g.* tunnels containing HLW and spent fuels and vaults containing ILW). In future DSSCs, there will need to be some form of demonstration that adverse interactions can be kept to insignificant levels. This would be based on an understanding of the variables that may control the minimum physical separation (vertical and lateral) required to ensure little adverse interaction for a range of hydrogeological conditions.

168. In report 048 there are statements that "*the geological barrier can provide one or more helpful functions in ensuring the safety of disposal* " and "*we will only know which… …*

we can rely on when we have … … a candidate site". This seems to not recognise that the geological barrier must provide effective containment for long-lived radioactive waste.

169. It is important that the potential dangers of high groundwater transmissivity zones have been recognised (report 048). However, more consideration is required as to how these might affect safety once the proposed engineered mitigation measures have failed. It is not just a design feature or consideration, but a more fundamental safety consideration.

170. Although outlines are provided for backfilling and sealing disposal vaults and tunnels, relatively little thought seems to have been given as to how the other underground facilities (like transfer cells) and equipment will be decommissioned, dealt with or sealed up for closure and long-term safety, other than that they will be filled with "mass backfill". These engineered facilities will have implications for the backfill strategy.

171. More consideration may need to be given to the proposals to use a single drift tunnel for high strength and low strength sedimentary host rocks. It will be important to have plans that incorporate design features of other long transport tunnels, such as the Channel Tunnel, put in place to manage events such as vehicle fires, power outages and collisions.

APPROACH TO IDENTIFYING R&D REQUIREMENTS

Current R&D Strategy and Programme

172. The current RWMD R&D programme is generic. As the implementation of geological disposal proceeds, RWMD's generic R&D will diminish and its rock-type and site-specific R&D will increase. The Status Reports identify gaps in generic knowledge and topics that are best tackled on a rock-type specific or site-specific basis.

173. CoRWM recognises that some of the current RWMD R&D programme was put in place before the Status Reports were written. It would not, therefore, be expected to fill all the generic knowledge gaps identified in the Status Reports. Nevertheless, there is a reasonably good correlation between the topics and priorities in the R&D programme and the knowledge gaps in the reports.

174. CoRWM has not examined RWMD's current R&D programme document and is therefore unable to comment on progress with commissioning gap-filling research. The Committee notes that RWMD is in the process of devising means to assess the success of its R&D in filling knowledge gaps. Such means are essential to the successful implementation of RWMD's Technical Strategy.

175. CoRWM commends RWMD for its positive engagement with Learned Societies on R&D issues. It is important that this continues.

Future R&D Strategy and Programme

176. CoRWM has been informed that the processes that RWMD intends to use to establish future R&D requirements include:
- extensive consultation on a revised R&D Strategy;
- extensive consultation on a revised R&D Programme;
- identifying topics through the RWMD Issues Management Process;
- various national and international conferences (organised by RWMD and by others);
- specialist meetings on particular topics;
- maintaining awareness of R&D programmes in other countries;

- participating in international R&D programmes.

177. The intention is to produce updated Status Reports in 2014, when the current generic R&D is complete. The revised R&D Strategy and R&D Programme are expected to be more focused on particular geological settings, in keeping with future stages of the GDF siting process. It will be important to make it possible to follow and audit changes to the R&D Programme through the work and outcomes into the revised Status Reports.

178. CoRWM considers that RWMD's planned approach to identifying future R&D requirements is sound in principle. However, much will depend on how it is carried out in practice. For example, CoRWM would encourage RWMD not to be too prescriptive about the scope and objectives of specialist workshops but to enable participants to influence the definitions of issues, as well as suggesting R&D to investigate them. CoRWM would also encourage RWMD to take full account of lessons learned from the 2011 Loughborough conference (NDA, 2011b) when it organises or helps to organise future conferences (CoRWM doc. 2986).

Approach to R&D

179. It is essential that RWMD has the capability to act as an intelligent client for R&D. The gDSSC documents, particularly the Status Reports, show that RWMD does have this capability in many of the relevant topic areas. However, there are a few topic areas, mainly related to the geological barrier and site characterisation, for which this is not the case. CoRWM emphasises that this does not mean that RWMD does not have this capability, only that it has not demonstrated that it has it *via* the gDSSC documents.

180. CoRWM notes that it would be unwise for RWMD to give the impression that it regards future R&D in any of the DSSC topic areas as confirmatory or as simply acquiring data. The role of R&D should also be to explore the issues and find out more, for example to develop improved technologies, models and understanding.

181. Maintaining awareness of R&D in other countries and participating in international R&D programmes are essential components of RWMD's work. CoRWM would encourage RWMD to play as active a part as possible in international projects, not to merely fund contractors to take part and review the results when the projects are complete. It would also encourage RWMD to second staff to other countries for substantial periods, so as to gain a full understanding of knowledge obtained elsewhere and its potential to be applied in the UK.

SITE CHARACTERISATION

Site Characterisation Strategy

182. RWMD has explained to CoRWM that its site characterisation project is about identifying what information is needed to satisfactorily characterise a site for a range of geologies and disposal concepts. Also, part of this project is a comprehensive review and evaluation of the methods and technologies for acquiring the necessary data.

183. Site Characterisation R&D needs were published early in February 2011. The next step was to ask the ESC team and the Engineering Design team what data they would require from a site characterisation programme. These would be used to define the project. Once a specific site is identified the project would be refined to focus on a specific geology and GDF concept. The site characterisation needs were set out in RWMD's R&D Programme Overview (report 073). However, these do not precisely match the needs set out in the subsequent Site Characterisation Strategy and Status Report (reports 017 and 057).

184. RWMD distinguishes between R&D and technical needs. By way of illustration, a requirement to develop a completely new technique would entail R&D and be described as such, whereas a need to identify the most suitable established technique would be described as technology identification or technology transfer. Site characterisation 'further work' could also be regarded as an 'unpacking' of the high-level needs listed in the R&D Programme Overview. Another interpretation is that site characterisation R&D is simply a subset of the overall technical work needed for site characterisation.

185. CoRWM considers that clarity and consistency is required between the needs identified in all documents. RWMD will rely on specialists in the supply chain to identify what information can be obtained during site characterisation and the best techniques for producing it. Thus it is important for the R&D and technical needs to be clearly identified, articulated and explained.

186. CoRWM considers that the phased approach to site investigation, from non-invasive geophysics to exploratory boreholes, will in reality be a phased and iterative process involving a combination of geophysics and exploratory borehole work, some of which may be carried out in parallel. This phased integration is not fully explored in the strategy.

187. It is stated that the integration of underground investigations with facility construction proposed for MRWS Stage 6 will have 'significant benefits'. (The meaning of 'integration' in this context, in the gDSSC, is proceeding with construction while continuing to carry out underground investigations.) However, the Site Characterisation Strategy (report 017) does not discuss or demonstrate what the benefits are in terms of characterisation and understanding. Conversely, any potential disadvantages of conducting extensive construction works before the results of a comprehensive programme of underground investigations are fully analysed are not assessed. The Site Characterisation Strategy would be improved by the inclusion of a full analysis of the potential advantages and disadvantages of the proposed approach.

188. The review of techniques is limited by its restriction to examining only those surface-based site investigations being conducted by other WMOs or past UK programmes (Nirex, UKAEA). Whilst being relevant and sensible programmes to consider, these do not cover the range of characterisation approaches or technologies employed globally. Whilst the use of a wide range of techniques across a range of sectors (oil, gas and mineral exploration) is noted, the Site Characterisation Strategy does not place any emphasis on investigating and assessing these to see where the leading advances are (*i.e.* in which sectors) and then adopting or adapting these.

189. The concept of a Site Descriptive Model is in principle an effective and useful means of presenting and demonstrating the suitability (or otherwise) and scale of suitability of a site. However, this is only true if the interactions between the component parts and discipline-based aspects of the system (geology, hydrogeology, hydrogeochemistry, geotechnical, transport properties, thermal properties and biosphere) are clearly described and analysed in the integration. The Site Descriptive Model presentations therefore will need to include material on the interactions and parameterisations of those interactions.

190. Site characterisation iterations will increase understanding of a site but may not reduce uncertainties. This requires repeated emphasis in future DSSC documents. Improved understanding may show that it is not possible, for example, to model variations in a key parameter realistically or determine flow paths and predict their evolution. In such a case the site would be unsuitable.

191. The Strategy states, in line with the 2008 MRWS White Paper (Defra *et al.*, 2008), that underground investigations will aim to ”confirm a site’s suitability…”. The use of ‘confirm’ is unfortunate as it suggests that the opposite outcome is not considered to be a possibility, even though surface-based geophysical investigations can only provide a limited amount of information and surface area of deep geological material.

192. RWMD proposes that successful completion of a site characterisation project is marked by the generation of an ‘adequate level of understanding’, following iterative and recursive investigations. An important requirement is to define what is meant by ‘adequate level’, how it is recognised, and what process will be put in place to review and evaluate this independently.

193. The quality management, data management, project controls and risk management aspects of the Site Characterisation Strategy (described in outline in report 017) are consistent with current good or best practice.

Site Characterisation Status Report

Stages in Characterisation

194. From its review of the Site Characterisation Status Report (report 057), CoRWM notes that the progressive development of understanding derived from cycles of site investigations should include an explicit stage of blind validation before deciding that site investigation is sufficiently complete. Otherwise, final understanding will always be calibrated to available data and therefore not demonstrated as adequate for predictive purposes.

Records Management

195. It is important to record the logical progression of evidence that underpins a particular data interpretation. For example, it is extremely common in the oil industry to return to old oil fields and be given interpreted seismic images with no record of why they were interpreted in a particular way. Often that interpretation was related to local experience derived from other sources. Capturing that type of experience and knowledge is a challenge, but is made considerably more straightforward if the record of evidence is maintained from the outset.

Geological Mapping

196. Ideally, structural geological interpretations (maps and 3D-to-4D models) should be clearly linked to the available observation data from which they were derived. This may not be possible in the early stages of site characterisation, when few, if any, observations have been made at depth.

Novel Site Characterisation Techniques

197. CoRWM considers that it is important that RWMD considers the use of the full range of site characterisation techniques and does not confine its attention to a sub-set made up only of those that are well-established. It is clear that tried and tested techniques should be used where they are entirely adequate. However, CoRWM considers that RWMD will probably need to make use of techniques that are currently under development. Examples are:

- Micro-seismic monitoring, which has the potential to be used for permeability estimation and ‘imaging’ of subsurface fractures in 3D and is being investigated by the hydrocarbon industry both for monitoring cap and reservoir rocks for hydrocarbon exploitation and for monitoring leakage from carbon storage reservoirs;

- Cross-hole underground electromagnetic methods, which are being developed for exploration in the hydrocarbon industry and complement micro-seismics in that they enable imaging of variations in electrical conductivity, which may be linked to changes in groundwater composition, rock permeabilities or micro-fracture networks;
- State-of-the-art tracer testing using 'geophysical' tracers, *i.e.* those that can be detected in three dimensions by their magnetic or electrical properties (*e.g.* saline fluids).

Underground Investigations

198. It appears from the Site Characterisation Status Report (report 057) that underground investigations will be planned on the premise that they will be confirmatory. CoRWM understands that it was not RWMD's intention to give this impression and welcomes this clarification.

199. Underground investigations will increase the accessible rock surface from which to characterise heterogeneity of the geological barrier by 1-2 orders of magnitude compared with exploratory boreholes. It is highly likely that this will lead to a substantive change in understanding. It is therefore appropriate to plan for a major programme of underground site investigation.

200. If appropriately planned, the access provided by underground work can be used to perform 'blind' validation, as described in the Site Characterisation Status Report. This is particularly valuable for a complex geology with heterogeneous structures and multiple episodes of flow of geochemically distinct groundwaters and hence multiple phases of low-T mineralisation.