An International Peer Review of the Biosphere Modelling Programme of the US Department of Energy’s Yucca Mountain Site Characterization Project

Report of the IAEA International Review Team

INTERNATIONAL ATOMIC ENERGY AGENCY

AN INTERNATIONAL PEER REVIEW OF THE BIOSPHERE MODELLING PROGRAMME OF THE US DEPARTMENT OF ENERGY'S YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

In March 2000, the United States Department of Energy (DOE) requested the International Atomic Energy Agency (IAEA) to organize an international peer review of the biosphere modelling programme being conducted in support of the Total System Performance Assessment of the Yucca Mountain Site Characterization Project.

The IAEA accepted the invitation and the review was carried out, in the period September 2000 to January 2001, by a team of experts invited by the IAEA, referred to as the International Review Team (IRT). The review included an examination of relevant DOE contractor documents, presentations of the work by the DOE during which the IRT questioned DOE and contractor staff, and a visit by the IRT to the environs of the Yucca Mountain Site.

The International Review Team (IRT) has tried to ensure that all information in this report is accurate and it takes responsibility for any factual inaccuracies.

The report presents the consensus views of the members of the IRT, and offers the DOE an independent, international perspective on its Yucca Mountain Biosphere Modelling Programme.

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SUMMARY AND RECOMMENDATIONS

BACKGROUND

S01. The United States Department of Energy (DOE) Yucca Mountain Site Characterization Project is currently developing and applying a methodology for the Total System Performance Assessment (TSPA) of a possible disposal facility for radioactive waste at Yucca Mountain, Nevada. An important part of this task is to develop and apply a methodology for assessing the potential impact of any releases of radionuclides that may reach the surface environment or 'biosphere' in the future. This is a comparatively new area for work within the DOE programme and, also, an area in which progress has been made in international fora in recent years. Recognizing this, the DOE requested the International Atomic Energy Agency (IAEA) to organize an independent international expert review of the biosphere assessment methodology and capability developed within the Yucca Mountain Site Characterization Project.

S02. The International Atomic Energy Agency (IAEA) is one of the United Nations family of organizations. The IAEA's main statutory functions are to establish standards of safety for the protection of human health against the effects of ionizing radiation and to provide for the application of these standards, at the request of a State, to any of that State's activities in the field of atomic energy. In discharging these functions, the IAEA has established a corpus of internationally agreed radiation and waste safety standards, including guidance on the safety assessment of radioactive waste repositories and, in particular, on evaluation of the biospheric components of those assessments. The IAEA also routinely responds to requests from its Member States to advise on the application of these safety standards to specific situations. The IAEA therefore accepted the request and organized the review.

S03. This publication is the report of the International Review Team (IRT) and represents the consensus views of the international experts as developed during the review process.

THE REVIEW

Objective and conduct of the review

S04. The objective of the peer review is to provide, on the basis of available international standards and guidance, an independent evaluation of the biosphere assessment methodology developed by the US DOE’s Yucca Mountain Site Characterization Project.

S05. The International Review Team (IRT) assembled by the IAEA consisted of six members from national advisory bodies, waste management organizations and regulatory bodies, plus a Scientific Secretary from the IAEA and a consultant to assist in documenting the review.

S06. The review was carried out between September 2000 and January 2001 with the most intensive work taking place during a one-week meeting in Las Vegas at the end of November 2000. The review included examination of DOE contractor documents, presentations of the work by the DOE at which the IRT was able to question DOE and contractor staff, a visit by the IRT to the Yucca Mountain and Amargosa Valley region, and closed discussion meetings of the IRT. Representatives of local stakeholder groups attended both the presentations by the DOE and also a close-out meeting at which the Chairman of the IRT made an oral presentation of preliminary observations and recommendations of the review to DOE representatives and observers.

S07. The main input documentation for the review was the “Biosphere Process Model Report” (PMR) and its sixteen supporting “Analysis and Model Reports” (AMRs). In addition, the IRT selectively examined a number of documents as background to the review, including the proposed regulations applicable to the Yucca Mountain facility. The Biosphere PMR and AMRs examined were version ‘Rev.0’ documents, recording DOE work as of May 2000, whereas material presented orally to the IRT drew on more recent work by the DOE. The IRT used the evidence of the Rev.0 documents and the presentations based on more recent work to make their evaluation of the DOE’s assessment methodology and capability, which, it is important to recognize, is still being developed.

S08. The review is an independent exercise and has no status vis-à-vis the regulatory process in the USA. The views expressed are those of the individual IRT members and not necessarily of their parent organizations, nor of the IAEA. The report has been checked for factual accuracy by the DOE, but any errors remain the responsibility of the IRT.

Approach to the review

S09. The DOE has developed a biosphere assessment capability that is focused on the eventual requirement of providing input to a TSPA compliant with the Yucca Mountain-specific regulations that are, as yet, at the proposal stage. In order to fairly represent and evaluate what the DOE has done, the IRT has identified in its observations where the focus on regulatory compliance has constrained the DOE approach and has divided its recommendations and suggestions into two classes. These are:

— recommendations and suggestions for improvement of the biosphere assessment capability while remaining focused on satisfying the regulatory requirements, and

— recommendations and suggestions for activities outside the regulatory requirements to contribute to the confidence of other stakeholder groups and, also, to bring the DOE's biosphere assessment closer to consistency with international guidance and practices.

S10. The IRT observes that although it will be essential to satisfy the regulators, it will also be necessary to present information and results of interest to other stakeholders, including representatives of local communities, scientific audiences, political decision makers and the general public. The wider activities should increase the confidence in DOE's understanding of the biosphere system performance, broaden the base of safety illustration and arguments and thus, also, increase the defensibility of the analysis for regulatory compliance.

S11. In recent years there have been discussions and developments at an international level that are relevant to the review. Section 2 of the main report briefly outlines some of these developments, although their dynamic character should be recognized. In particular, attention is drawn to:

— publications from the International Commission on Radiological Protection (ICRP) which provide guidance on the adaptation of the ICRP radiological protection system to protection in relation to the disposal of solid long-lived radioactive waste;

— the IAEA BIOMASS programme[1], which has developed a methodology for the construction of biosphere models for long-term safety assessments and also provided worked examples of the application of the methodology;

[1] An international programme on BIOsphere Modeling and ASSessment launched in 1996. The programme is addressing radiological issues associated with the accidental and routine releases of radionuclides to the environment, and solid waste disposal.

— developing views on the assessment of environmental protection in the context of the disposal of long-lived radioactive waste.

S12. The IRT commends the documents referenced in Section 2 as providing information and guidance that may be of value to the DOE in developing its biosphere assessment programme in future years. The documents also provide a background from which the IRT presents its observations and recommendations.

S13. In the following sections, the IRT summarizes the recommendations and suggestions that they invite the DOE to consider in the future development and application of a biosphere assessment capability for the Yucca Mountain site. These are drawn directly from the text of the main report so that their context and basis can be examined therein.

RECOMMENDATIONS AND SUGGESTIONS

For improvements to the biosphere assessment capability while remaining focused on satisfying the regulatory requirements

S14. The IRT recommends (§316) that the DOE should, in future, consider more fully the possible aims of biosphere assessment within the Yucca Mountain Site Characterization Project both within and outside the regulatory framework. Possible expanded aims might be:

— To identify and investigate the role of environmental, including site-specific, processes that may be relevant to the environmental accumulation and distribution of radionuclides in the long-term, uptake into foodstuffs and other exposure pathways.

— To investigate a range of potential exposure scenarios and circumstances in order to support arguments for the adequacy of exposure scenarios defined by regulation, or identify alternative or supplementary exposure scenarios.

S15. The assumption that BDCFs are concentration-independent (§328) is not unreasonable for the trace quantities of radioisotopes that are expected to be released to the biosphere. It is such an important assumption, however, that it would be wise to test the limits of the validity of the assumption. That is, the circumstances and radionuclides for which concentration-dependent effects may occur should be identified, and checks made on whether the TSPA results enter into these regions.

S16. The IRT recommends (§331) that, in future, the consideration of the biosphere is more fully integrated into the total system conceptual model. This is scientifically desirable for the development of the total system model on all timescales, but may have greater potential for practical implications that feed on to the calculation models when considering the total system performance over timescales beyond the 10,000 year time frame. This does not imply that a coupled modelling capacity is required, rather, that the interactions are more fully considered in the system conceptualization and definition of scenarios.

S17. The IRT recommends (§405) that the DOE should consider a programme of biosphere characterization including on-site measurements. The IRT considers that the examination of site-specific biosphere characteristics and processes, especially related to soil and its potential development, is especially important for the Yucca Mountain Project which is considering an environment unlike most other biosphere environments considered in geological disposal assessment. The information could help assess the applicability to this environment of biosphere data that are available from other sources and otherwise assist in the selection and justification of data.

S18. Regarding the diet and habits that should be assigned to a RMEI[2] or critical group for compliance assessment, the IRT considers (§414) that the DOE has placed too great a significance on habits determined from the 1997 survey. The IRT recommends (§415) that it would be prudent for the DOE to consider all human activities that might reasonably and consistently occur and to consider cautious but not extreme dietary intakes and exposure times. The 1997 survey is one input to this consideration and it would be desirable to update the survey so as to augment the available survey information.

S19. The IRT recommends (§504) that the DOE should consider how best to capture and use the existing scientific and local knowledge regarding the biosphere. For example, the DOE could consider a workshop, or other form of site-specific elicitation of relevant features, event and processes (FEPs) for the biosphere, in which a range of scientific and local expertise is coordinated. The regulatory guidance should not be considered or used to constrain the scope of any such elicitation. Rather, regulatory guidance should only be used in a subsequent stage of screening if necessary.

[2] Reasonably Maximally Exposed Individual — a term defined by the US Environmental Protection Agency.

S20. The IRT recommends (§507) that the DOE should examine the methods of conceptual model construction described, for example, in the BIOMASS documentation and in national assessment studies, with a view to devising a method that more clearly tracks the incorporation of individual FEPs into the biosphere model. An alternative approach, that may be valuable, is to audit the biosphere conceptual model as it is represented in the selected software against the list of potentially-relevant FEPs with a view to identifying biases due to omission or simplification.

S21. The IRT recommends (§513) that the DOE should consider implementing future biosphere conceptual models using more flexible simulation tools. In practice, relatively few components need to be represented dynamically and for the chronic contamination situations considered in the regulatory scenarios the calculation of crop and animal uptakes and human exposure can generally be done in spreadsheets assuming that equilibrium concentrations are reached.

S22. The IRT recommends (§516) that in future iterations of the biosphere assessment documentation, the consistency of the parameters with the assumptions made in the biosphere model as well as with the site-specific conditions found in Amargosa Valley should be considered and discussed in more detail. This will improve the scientific credibility of the biosphere assessment and, also, allow the DOE to more properly claim that the assessment is indeed site-specific.

S23. On specific points, the IRT suggests (§518) that:

- The K_d approach to modelling the migration of radionuclides in soil should be re-evaluated.
- The soil characteristics in Amargosa Valley and the problems of application of transfer factors to estimate root uptake should be addressed.
- The sustainability of irrigation assumed for the regulatory scenarios should be discussed.
- The resuspension and deposition of soil particulates and subsequent doses due to their inhalation should be investigated. This may be especially important for the volcanic ash deposit scenario.
- The implications of applying more modern dosimetric data should be tested, especially since this data is widely adopted internationally through the IAEA Basic Safety Standards.

S24. The IRT suggests (§526) that the DOE should re-assess the treatment of uncertainties in the biosphere with regard to the aims of assessment and consider the uncertainties that should be:

— represented in the regulatory exposure scenarios within the TSPA;

— investigated in the regulatory exposure scenarios and model in standalone mode;

— explored through alternative models and scenarios.

S25. In addition (§526), the DOE should discuss more fully the uncertainties due to the scenario specification, model choice and parametric uncertainties, set out the rationale for the selected approach to biosphere uncertainty (both within and outside the regulatory framework) and explain the limitations of the approach and consequent results.

S26. The IRT recognizes QA as an essential requirement within an assessment that is to be submitted in support of a license application. The IRT recommends (§531) that the DOE examines the existing QA procedures and their application to assessment activities with a view to ensuring the procedures maintain a balance between providing the formal assurance required while not unnecessarily constraining the technical work.

S27. The IRT suggests (§534) that the use of expert judgment should be made more overt, e.g. through adequate documentation of scientific discussions and arguments, and that expert scientific and technical judgments should be used in parallel with the formalized QA criterion approach. The IRT observes that staff quality and the time to consider and record the necessary scientific and technical judgments, are essential factors in producing a quality assessment.

For activities outside the regulatory requirements

S28. The IRT suggests (§322) that it would be prudent for the DOE to satisfy itself that the constraints imposed for compliance assessment do not lead to the neglect of potentially significant uncertainties, processes and interactions that might be considered in a wider context, including a fuller safety assessment. In particular, it cannot be argued that an approach is cautious unless a range of other circumstances and exposure scenarios have been considered and shown to lead to lower calculated doses and or risks.

S29. The IRT recommends (§323) that:

— a sufficiently broad examination of possible release pathways and related exposure situations should be examined to identify and justify the more closely-defined case adopted for compliance demonstration, and that

— logical extensions of the compliance case and alternative or supplementary situations should be considered to place the case in perspective and to assess the level of bias against a broader spectrum of possible cases.

S30. The IRT suggests (§408) that the DOE should identify and evaluate a range of alternative and supplementary biosphere scenarios. In some cases, the scenarios may only require minimal discussion to dismiss as unlikely to occur or unlikely to lead to any significant exposure, but identification and discussion of other possibilities would greatly increase the confidence in the completeness of the DOE's assessment. In other cases, more detailed consideration or calculations may be required to evaluate the pathway. Presentation of such cases, over and above those required to satisfy regulatory requirements, would enrich the overall DOE presentation and safety arguments.

S31. The IRT recommends (§417) that the DOE continues to estimate performance for times beyond the time frame required for regulatory compliance. The DOE should take the opportunity to present assessments that might be more directly comparable with the style of other national assessments, e.g. considering farming communities appropriate to alternative projected future climate conditions. The habits of the indigenous American tribes, as practiced in past times and at different locations, might provide a useful model.

S32. The IRT suggests (§418) that, especially in the longer time frame, the DOE could present a number of complementary performance indicators that are less dependent on the assumptions concerning human habits. These might include a drinking water (only) pathway that would be applicable over a wide range of biosphere conditions, as well as the increase in concentration of radionuclides in the surface environment. The latter might be compared with the level and variability of naturally-occurring radioactivity in the environment, e.g. in terms of total alpha and total beta activity.

S33. The IRT recommends (§423) that, if a fuller examination of the volcanic event scenario is undertaken, this should include a properly justified selection of the location and habits of the RMEI or critical group (or alternative RMEIs and groups) appropriate to the scenario. The IRT also recommends that, in presenting the TSPA results for this scenario, the stylization of the scenario and the illustrative character of the results should be emphasized.

S34. The IRT suggests (§514) that, even if the DOE decides to retain the GENII code to calculate impacts for regulatory compliance, additional, more flexible models could be used to investigate aspects of biosphere performance and, also, to assess the potential bias associated with the model represented by the GENII code.

S35. The IRT suggests (§528) that even if probability-weighted dose is the main output required by the regulator, it would be desirable to present disaggregated information (doses and probabilities). This information would more clearly illustrate the nature of the potential impact, so as to better inform decision-makers and other interested audiences. For example, a useful complementary presentation would be the dose profiles conditional on an event occurrence at selected times.

S36. The IRT suggests (§537) that during the more thorough characterization of the biosphere (see §S16), the DOE should look for opportunities to obtain field data that would enable some degree of model testing, or otherwise support the model. Candidate data could include measurements of trace elements, nuclear fallout or natural radionuclides and their disposition in local soils and plants.

FINAL REMARKS

S37. By commissioning this international peer review of its biosphere assessment programme the DOE has demonstrated a commendable openness and commitment to improving the confidence in future iterations of its TSPA. The review is intended as constructive criticism as an aid to the future development of the DOE's biosphere programme based on an international perspective. The IRT acknowledges, however, that the DOE is best placed to determine the value and priority of the recommendations within its specific regulatory and national context. Thus, the decisions to implement changes, or not, and decisions on the relative priority of the recommended developments rest with the DOE.

1. INTRODUCTION

1.1. BACKGROUND

101. The United States Department of Energy (DOE) Yucca Mountain Site Characterization Project is currently developing and applying a methodology for the Total System Performance Assessment (TSPA) of a possible disposal facility for radioactive waste at the Yucca Mountain site, Nevada. An important part of this task is to develop and apply a methodology for assessing the potential impact of any releases of radionuclides that may reach the surface environment or ‘biosphere’[3] in the future. This is a comparatively new area for work within the DOE programme and, also, an area in which progress has been made in international fora in recent years. Recognizing this, the DOE requested the International Atomic Energy Agency (IAEA) to organize an independent international expert review of the biosphere assessment methodology and capability developed within the Yucca Mountain Site Characterization Project. The review was commissioned with the view to assessing the current biosphere assessment approach and capability, and giving advice on possible developments and improvements that could benefit the DOE programme in future iterations of the TSPA.

102. The International Atomic Energy Agency (IAEA) is one of the United Nations family of organizations. The IAEA’s main statutory functions are to establish standards of safety for the protection of human health against the effects of ionizing radiation and to provide for the application of these standards, at the request of a State, to any of that State’s activities in the field of atomic energy. In discharging these functions, the IAEA has established a corpus of internationally agreed radiation and waste safety standards, including guidance on the safety assessment of radioactive waste repositories and, in particular, on evaluation of the biospheric components of those assessments. The IAEA also routinely responds to requests from its Member States to advise on the application of these safety standards to specific situations.

[3] In this report the biosphere is defined as the natural and human environment in which the significance of radiological impacts resulting from potential radionuclide releases from the repository needs to be assessed. The biosphere consists of the region of the surface and near-surface environment into which radionuclides may be released, including local and possibly more distant features in which radionuclides may accumulate, and the natural processes and human activities taking place in this region.

103. The IAEA therefore accepted the request and organized the review. This document is the report of the International Review Team (IRT) and represents the consensus views of the international experts as developed during the review process.

1.2. OBJECTIVE AND TERMS OF REFERENCE FOR THE REVIEW

104. The objective and Terms of Reference for the review were agreed between the DOE and the IAEA.

> The objective of the peer review is to provide, on the basis of available international standards and guidance, an independent evaluation of the biosphere assessment methodology developed by the US DOE's Yucca Mountain Site Characterization Project.

105. The Terms of Reference for the peer review are set out in Appendix I. In summary, the IRT is charged with reviewing the biosphere assessment methodology being used for the TSPA of the Yucca Mountain disposal facility. This is with the purpose of critically analyzing the proposed rationale and methodology and of identifying consistencies and inconsistencies between methods being used in the frame of the DOE's project and those being established in international guidance or practices, for example, in the IAEA's BIOMASS programme[4].

1.3. THE INTERNATIONAL REVIEW TEAM

106. The International Review Team (IRT) assembled by the IAEA included six members from national advisory bodies, waste management organizations and regulatory bodies. The team was completed by a Scientific Secretary from the IAEA and an independent consultant to assist the IRT Chairman and the IAEA in documenting the review. All members, including the latter two, made technical contributions to the review.

[4] An international programme on BIOsphere Modelling and ASSessment launched in 1996. The programme is addressing radiological issues associated with the accidental and routine releases of radionuclides to the environment, and solid waste disposal.

107. The IRT was chaired by Professor Roger Clarke, the Director of the UK National Radiological Protection Board. The names of the members and summaries of their experience are provided in Appendix II.

108. None of the members of the IRT had ever worked on the Yucca Mountain Site Characterization Project but most had some background knowledge of the project via participation in international meetings. The team included members with experience in the development of relevant guidance from the International Commission on Radiological Protection (ICRP) and members who participated and have taken leading roles in the IAEA's BIOMASS programme and, earlier, BIOMOVS studies.

1.4. THE CONDUCT AND SCOPE OF THE REVIEW

109. The review was carried out between September 2000 and January 2001 with the most intensive work by the IRT taking place during a one-week meeting in Las Vegas at the end of November 2000. The review included:

- examination by IRT members of DOE contractor documents describing the biosphere assessment work and recording of preliminary individual comments;
- presentations of the work by DOE and contractor staff at which the IRT was able to question the staff;
- a visit by the IRT to the Yucca Mountain and Amargosa Valley region;
- closed discussion meetings of the IRT and examination of supplementary documents requested by the IRT.

110. Representatives of local stakeholder groups attended both the presentations by the DOE and contractors, and also a close-out meeting at which the Chairman of the IRT made an oral presentation of preliminary observations and recommendations of the review to DOE representatives and observers.

111. The conduct of the review is presented in more detail in Box 1.

112. The main input documentation for the review was the "Biosphere Process Model Report" (PMR) [1] and its sixteen supporting "Analysis and Model Reports" (AMRs) and Calculation Reports, see Box 2. In addition, the IRT selectively examined a number of documents as background to the review. These included the proposed regulations applicable to the Yucca Mountain facility and related

Box 1: Conduct of the review

The IAEA identified a balanced panel of international experts to undertake the review – the IRT – and appointed the Chairman for the review in August 2000. A documentation package was sent to IRT members who responded with preliminary comments and questions, which were forwarded to the DOE.

A meeting of the IRT Chairman, IAEA representative and consultant took place in October 2000. At this meeting the individual comments were reviewed and collated, and an agenda for presentations by the DOE and its contractors was drawn up.

During the last week of November 2000, the IRT assembled in Las Vegas, Nevada, for a one-week period. During this week:

- The IRT received presentations from the DOE and contractors according to the proposed agenda and designed to address their preliminary comments and questions. The presentations included summaries of the regulatory and programmatic context of the work and more recent technical developments. The IRT was able to ask detailed questions and request further documents to satisfy particular concerns. Invited observers representing local stakeholder groups attended these sessions and participated in the discussions.

- The IRT made a one-day visit to the Yucca Mountain site and Amargosa Valley with DOE and contractor staff. The IRT had the opportunity to study the proposed repository site and its surroundings including the location near the junction of US Route 95 and Nevada Route 373 identified in the EPA and NRC proposed rules, the Amargosa Valley including its farmlands, the Amargosa River and Franklin Lake Playa.

- The IRT held closed discussion sessions at which the experience of the presentations and site visit were analyzed and preliminary observations and recommendations were developed. The structure of a final report was also developed and preliminary observations and recommendations organized in this structure.

- On the final morning, the IRT chairman made a short oral presentation to DOE representatives and other observers. This presentation included the preliminary observations and recommendations of the IRT.

During December a first full draft of the Review report was developed and circulated to the IRT members for comments. The report was refined taking account of team comments and, at a meeting in January 2001, the IRT chairman and IAEA approved changes for a draft report to be submitted to the DOE for comments on factual accuracy.

Minor changes related to factual accuracy and typography were suggested by the DOE and have been accommodated in producing this final report.

background [2–4], and the DOE's TSPA Viability Assessment and related reviews [5–7]. These documents are also listed in Box 2.

113. The Biosphere PMR and AMRs examined were version 'Rev.0' documents, recording DOE work as of May 2000, whereas material presented orally to the IRT while in Las Vegas drew on more recent work by the DOE in developing 'Rev.1' documentation, and one draft Rev.1 AMR was examined. The IRT used the evidence of the Rev.0 documents and the presentations based on Rev.1 to make their evaluation of the DOE's assessment methodology and capability, which, it is important to recognize, is still being developed.

114. The review is an independent exercise and has no status vis-à-vis the regulatory process in the USA. The views expressed are those of the individual IRT members and not necessarily of their parent organizations, nor of the IAEA. The report has been checked for factual accuracy by the DOE, but any errors remain the responsibility of the IRT.

1.5. APPROACH TO AND STATUS OF THE REVIEW

115. The DOE's biosphere assessment programme is a small part of a large study – the Yucca Mountain Site Characterization Project – which includes an iterative programme of Total System Performance Assessment (TSPA), e.g. see [5]. Some questions asked by the IRT inevitably crossed boundaries and required understanding of the wider programmatic context and TSPA findings. Nevertheless, in this report, the IRT's observations and recommendations are focused on aspects of the biosphere. Similarly, the biosphere assessment and modelling carried out by the DOE is conditioned by the proposed regulatory requirements. The peer review does not seek to question or comment on these, but does note some consequences of the regulations for the DOE's work in relation to international guidance and practice.

116. To date, the DOE has developed a biosphere assessment capability that is focused on what the DOE sees as the eventual requirement of providing input to a TSPA compliant with the Yucca Mountain-specific regulations that are, as yet, at the proposal stage [3, 4]. In order to fairly represent and evaluate what the DOE has done, the IRT has identified in its observations where the focus on regulatory compliance has constrained the DOE approach and has divided its recommendations into two classes. These are:

— recommendations for improvement of the biosphere assessment capability while remaining focused on satisfying the regulatory requirements, and

Box 2: Input documents for the review

The primary input documents for the review were the

Biosphere Process Model Report, Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&OC) DDR-MGR-MD-000002 Rev. 00 ICN 01, May 2000 [1]

together with its sixteen supporting Analysis and Model Reports (AMRs), Rev. 0:

- Evaluation of the Applicability of Biosphere-Related Features, Events and Processes (FEPs)
- Environmental Transport Parameter Analysis
- Transfer Coefficient Analysis
- Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)
- Identification of Ingestion Exposure Parameters
- Input Parameter Values for External and Inhalation Radiation Exposure Analysis
- Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods
- Evaluation of Soil/Radionuclide Removal by Erosion and Leaching
- Non-Disruptive Events Biosphere Dose Conversion Factors
- Non-Disruptive Events Biosphere Dose Conversion Factors Sensitivity Analysis
- Distribution Fitting to the Stochastic BDCF Data
- Abstraction of BDCF Distributions for Irrigation Periods
- Biosphere Dose Conversion Factor for Reasonably Maximally Exposed Individual and Average Member of Critical Group
- Disruptive Event Biosphere Dose Conversion Factor Analysis
- Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis
- Groundwater Usage by the Proposed Farming Community

In addition, the following documents were consulted as background to the review:

- the National Academy of Sciences report: Technical Bases for Yucca Mountain Standards [2]
- the proposed regulations applying to the Yucca Mountain facility: the EPA's proposed standard 40 CFR part 197 [3] and the NRC's proposed compliance requirements 10 CFR Part 19 et al. [4]
- the DOE's Total System Performance Assessment Viability Assessment (TSPA-VA) [5]
- the OCRWM's Peer Review Panel report on the TSPA-VA [6]
- the NRC's TSPA and Integration Issue Resolution Status Report, Revision 3, September 2000 [7]

— recommendations for activities outside the regulatory requirements to contribute to the confidence of other stakeholder groups and, also, to bring the DOE's biosphere assessment closer to consistency with international guidance and practices, e.g. as discussed in Section 2 of this report.

117. The IRT observes that although it will be essential to satisfy the regulators, it will also be necessary to present information and results of interest to other stakeholders, including representatives of local communities, scientific audiences, political decision makers and the general public. The wider activities should increase the confidence in DOE's understanding of the biosphere system performance, broaden the base of safety illustration and arguments and thus, also, increase the defensibility of the analysis for regulatory compliance.

2. INTERNATIONAL PERSPECTIVE

201. In recent years there have been discussions and developments at an international level that have defined and established conditions that provide the context for the IRT's observations and recommendations. This section briefly outlines some of these developments, although their dynamic character should be recognized.

2.1. ICRP RECOMMENDATIONS

202. The International Commission on Radiological Protection (ICRP) has recently issued recommendations applicable to the disposal of radioactive waste in ICRP Publications 77 and 81 [8, 9]. Therein, the ICRP recognizes the challenges placed on the radiological protection system as defined in its 1990 Recommendations (Publication 60) [10] by the consideration of long time periods into the future, and provides guidance on the adaptation of the system to protection in relation to the disposal of solid long-lived radioactive waste.

203. ICRP Publication 81, in particular, gives relevant guidance not only on how radiological protection principles should be defined and interpreted, but also on the conduct of assessments of the long-term safety of repositories and the ways to achieve and judge compliance. For example, it is recommended that the objective of long-term performance assessment should not be to deduce the most probable radiological impact, but rather to provide well-founded arguments to support the conclusion that the disposal system can provide the required level of protection with a reasonable degree of confidence. Key paragraphs related to compliance are reproduced in Box 3, but a more general reading of the Publication is recommended.

2.2. THE IAEA BIOMASS PROGRAMME

204. Guidance for dealing with the biosphere component of repository performance assessment has been developed through Theme 1 of the IAEA BIOMASS programme, e.g. see [11–14]. The programme has involved participants from many national programmes, including regulators and implementors of radioactive waste disposal and independent experts. The work has resulted in the development of a methodology for the construction of "assessment biospheres", i.e. that part of integrated performance assessment that, in effect, converts radionuclide releases from a repository (fluxes and concentrations) into measures, or indicators, of potential harm. Usually, these measures of potential harm are dose and risk to humans, such as

Box 3: On compliance – selected paragraphs from ICRP Publication 81 [9]

(76) Demonstration that radiological protection criteria will be met in the future is not as simple as straightforward comparison of estimated doses/risks with the constraints. Proof that the disposal system satisfies criteria cannot be absolute because of the inherent uncertainties, especially in understanding the evolution of the geologic setting, biosphere, and engineered barriers over the long term. Adequate assessments should be scientifically sound, accommodate reasonable conceptual understandings of system behaviour, use stylised approaches and reasonably conservative assumptions as appropriate, and typically be peer reviewed by consulting experts. These assessments should also address the remaining uncertainties by means of suitable presentations of their results (e.g. as ranges of numbers or bounding estimates). Thus, a decision on the acceptability of a disposal system should be based on reasonable assurance rather than on an absolute demonstration of compliance.

(77) Evaluating whether there is compliance with the constraints requires a judgement. The dose/risk constraints should increasingly be considered as reference values for the time periods farther into the future. The constraints provide a basis for judgements. Numerical compliance alone should not compel acceptance of a proposed safety case. Adequate evidence of the quality of the supporting data and analyses should also be required, as well as an assessment that the overall design and construction of the disposal system comports with the technical and managerial principles cited above. By the same token, transgressions of constraints do not necessarily oblige rejection of a proposed safety case, merely because their value is estimated to be exceeded. The unquantified conservatism likely to be incorporated into a performance estimate should be recognised in evaluating performance estimates; as the time frame increases, some allowance should be made for assessed dose or risk exceeding the dose or risk constraint. This must not be misinterpreted as a reduction in the protection of future generations and, hence, a contradiction with the principle of equity of protection, but rather as an adequate consideration of the uncertainties associated with the calculated results. However, any transgression must be justified and the system's safety must be supported by other evidence or the reasons for the transgression must be evaluated to determine if additional measures would result in improved protection.

may be required to show regulatory compliance and to illustrate and facilitate the evaluation of the estimated level of protection provided by the repository.

205. An important part of the BIOMASS programme has been the application of the methodology to the development of a series of example "Reference Biospheres" [15, 16]. These example Reference Biospheres are designed to test the BIOMASS methodology and, also, to be useful in their own right. Firstly, they are generic to

allow them to be used in a variety of situations. Second, to maximize their usefulness, the examples are taken all the way through to a numerical endpoint, so demonstrating the practical use of numerical data. Together, the methodology and the example Reference Biospheres provide practical guidance and tools for use in the biosphere aspects of repository performance assessment.

2.3. ENVIRONMENTAL PROTECTION

206. An area of biosphere assessment that has received increased attention internationally in the last few years is the identification of endpoints other than human health, e.g. see [17, 18]. In particular, the need (or not) to identify non-human species that may be at risk from radiation sources, and to develop appropriate protection standards, is an active topic. The recent review by UNSCEAR of the effects of ionizing radiation on plants and animals provides useful background in this area [19].

207. ICRP Publication 81 [9] confirmed the view expressed in the ICRP's 1990 Recommendations [10] that: "the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk". Notwithstanding this view, the wider issue of environmental protection, including the potential assessment of doses to non-human biota is being considered in several countries. It is recognized that, in the context of repository post-closure assessment, calculated impacts to non-human species are indicator quantities, just as calculated doses to humans are indicator quantities. Such presentations may still be valuable as additional information to illustrate the estimated level of environmental protection.

208. The IAEA includes 'protection of the environment' as one of the principles of radioactive waste management in its Safety Fundamentals [20], and has examined the subject from a conceptual point of view as well as reviewing the national approaches to the subject in a recent technical document [21]. The topic is also being considered by a Task Group under the Main Commission of the ICRP. At present, however, there are no agreed international guidelines or recommendations that could have been offered for use by the DOE or any other organization for the purpose of assessing such effects.

2.4. RELEVANCE TO THE DOE AND TO THIS REVIEW

209. The IRT understands the importance of national regulations and appreciates that these can take direct account of local and national concerns and system-specific

factors. The national regulatory system must also take the pre-eminent role in setting the tests and criteria to be met in compliance assessments. Nevertheless, the IRT commends the documents referenced above as providing information and guidance that may be of value to the DOE in developing its biosphere assessment programme in future years. The documents also provide a background from which the IRT presents its views.

3. THE DOE’S BIOSPHERE ASSESSMENT APPROACH

301. This section examines the DOE’s approach to developing a biosphere assessment within the programmatic context and proposed regulatory framework with which the DOE has been presented.

3.1. THE NATIONAL AND PROGRAMMATIC CONTEXT

302. Yucca Mountain has been the object of intensive investigation since 1987 when, under the Nuclear Waste Policy Amendments Act, it was selected as the only site in the USA to be characterized as a potential location for the development of an underground repository for spent nuclear fuel and high-level radioactive waste. Since that time the DOE has developed a programme of site characterization guided by Total System Performance Assessment (TSPA) that is aimed at guiding the design of a potential facility and assessing the acceptability of the facility and site against national regulatory standards.

303. Up until 1992, the expected form of the primary standard to be applied was a probabilistic total release standard as set out in the EPA’s standard 40 CFR Part 191 and as assessed, for example, in the 1991 TSPA [22]. This considered releases to the accessible environment (5 km distant from the repository for aqueous-based releases, and to the surface above the repository for other releases).

304. In 1992, the Yucca Mountain site was exempted from the 40 CFR Part 191 disposal standard and the Energy Policy Act (EnPA) became law. Under this Act, the responsibility of the EPA to set public health and radiation safety standards for Yucca Mountain, and of the NRC to set compliance requirements based on these, was confirmed. In addition, the EPA was required to contract with the US National Academy of Sciences (NAS) to give findings and recommendations on reasonable standards for the protection of health and safety for the Yucca Mountain site. The uncertainty generated for the DOE can be gauged from the DOE’s 1993 TSPA which states that “Because we have no way of knowing what form the new standards for Yucca Mountain will take, our approach is to consider several possibilities ...” [23; p. 2–14]. In this assessment, total release was assessed for continuity with previous assessments but individual drinking water doses were also calculated for some scenarios.

305. The NAS report “Technical Bases for Yucca Mountain Standards” [2] was published in 1995. Inter alia, the report recommends the use of a standard that sets a limit on the risk to individuals of adverse health effects (radiological risk) from

Box 4: Environmental standards for Yucca Mountain – key paragraphs*

§197.20: The DOE must demonstrate, using performance assessment, that there is a reasonable expectation that for 10,000 years following disposal the reasonably maximally exposed individual (RMEI) receives no more than an annual committed effective dose equivalent of 150 microsieverts from releases from the undisturbed Yucca Mountain disposal system.

§197.21: The RMEI is a hypothetical person who could meet the following criteria:

(a) Based on current understanding, lives within one-half kilometer of the junction of U.S. Route 95 and Nevada State Route 373, unless NRC determines that the RMEI would received a higher dose living in another location at the same distance from the Yucca Mountain repository.

(b) Has a diet and living style representative of the people who are in the Town of Amargosa Valley, Nevada. The DOE must use accurate projections which might be based on surveys of the people residing in the Town of Amargosa Valley.

(c) Drinks 2 liters of water per day from wells drilled into the groundwater at the location where the RMEI lives.

§197.30: To complement the results of §197.20, DOE must calculate the peak dose of the RMEI that would occur after 10,000 years following disposal but within the period of geologic stability. No regulatory standard applies to this result but the result must be included as an indicator of long-term disposal system performance.

* The paragraphs are abbreviated in some cases, see [3] for actual text.

releases from the repository, the use of a critical-group approach and that compliance assessment be conducted for the time when the greatest risk occurs (within the limits imposed by the long-term stability of the geological environment). The report also concludes that “it is not possible to predict on the basis of scientific analysis the societal factors required for an exposure scenario”, and that “specifying exposure scenarios therefore requires a policy decision that is appropriately made in a rule making process conducted by the EPA.”

306. The EPA reviewed the NAS report and, as part of the review process, invited public comments and held public meetings, both to foster general discussion and to answer specific questions. These public views have been taken into account in the formulation of EPA’s proposed standards for Yucca Mountains, 40 CFR Part 197, proposed rule [3], issued for comment in August 1999. The document sets out in

detail various questions considered by the EPA in their rule making and an explanation of their choices. Key requirements that are most pertinent to this review are set out in Box 4.

307. The IRT observes that there is a strong chain of policy decisions, academic advice and, regulatory review with public participation, that leads to the definition of the assessment task that the DOE is obliged to undertake. The IRT considers that an ordered process, together with clearly defined organizational responsibilities, a clear decision process, and opportunities for input by stakeholders, are essential elements in the successful development of a controversial technological project requiring public acceptance, such as a repository for radioactive waste.

308. The IRT also observes that, whereas the DOE has been developing an integrated TSPA capability since 1987, the requirement to include within this capability an analysis of a biosphere component, in order to assess doses to potentially exposed humans, has only been apparent since about 1995. This has had two immediate impacts in the development of the DOE's biosphere assessment capability.

— First, that consideration of the biosphere and the biosphere capability is less mature than the major part of the TSPA capability which is concerned with performance of the engineered and geological barriers.

— Second, that the biosphere capability has been developed as a semi-independent or 'bolt-on' accessory to the TSPA.

309. This separation has been further encouraged by the prescriptive nature of proposed EPA standards and NRC compliance requirements regarding exposure scenarios (as recommended by the NAS). This prescription has removed from the DOE an incentive to explore further biosphere or exposure scenarios and the linkage to release scenarios in a wider context, e.g. as reflected in the international perspective (see Section 2).

3.2. AIMS OF THE DOE'S BIOSPHERE PROGRAMME

310. During the DOE presentations to the IRT, the aim of the biosphere programme within Yucca Mountain Site Characterization Project was given as:

> "To develop site-specific dose conversion factors that will permit calculation of radiation dose to the nearest receptor population due to the repository after its closure."

311. This is expanded on in the Biosphere PMR where it is stated that the objective of the Biosphere PMR is to summarize (1) the development of the biosphere model, and (2) the Biosphere Dose Conversion Factors (BDCFs) developed for use in the TSPA. The PMR also notes that the biosphere model is a component of the process to evaluate post-closure repository performance and regulatory compliance.

312. The IRT considers that the above aim is rather limited and, from an international perspective, would have expected to see a broader aim. For example, the Biosphere PMR might have referred to investigating relevant aspects of the biosphere, identifying and investigating processes that could be important in determining potential radiological impacts in the surface environment now and in the future, and the implications for site characterization and evaluation. By contrast, the limited aim of calculating site-specific BDCFs implies a view that the biosphere is a relatively simple and already well-known or well-understood system, not deserving of detailed investigation such as has been accorded to other aspects of the disposal system.

313. This may be a deliberate assessment choice, as is made in several other assessment programmes, that uncertainties related to the biosphere are largely irreducible and should not be a determinant in repository decision making. Therefore, it is argued, the biosphere should be treated in a stylized fashion to generate a 'measuring stick' by which to convert releases from the geosphere to measures of relevance for regulatory compliance, e.g. see [24, 25]. This is not argued in the DOE documents or presentations but would be consistent with the de facto position of the DOE in which compliance is carried out for hypothetical exposed individuals whose locations and habits are mostly prescribed by regulation.

314. Even if the hypothetical exposed group is defined, however, the processes by which radionuclides may accumulate and disperse in the local environment and locally-derived foodstuffs or other resources still deserve attention. The IRT observes that the Yucca Mountain surface environment is unlike any other that is currently being considered in geological repository post-closure assessments and that a more thorough investigation of site-specific biosphere processes might be necessary.

315. On balance, the IRT concludes that for a first-pass biosphere assessment, DOE has adopted a reasonable strategy of focusing on calculating the conversion factors required to calculate the doses to a RMEI or critical group member required by regulation, and thus update their existing TSPA capability. The IRT considers, however, that a conventional approach to incorporating a new component into safety evaluation should usually include stages of characterization, development of scientific understanding, development of conceptual and quantitative models as well as evaluation.

316. *The IRT recommends that the DOE should, in future, consider more fully the possible aims of biosphere assessment within the Yucca Mountain Site Characterization Project both within and outside the regulatory framework. Possible expanded aims might be:*

— *To identify and investigate the role of environmental, including site-specific, processes that may be relevant to the environmental accumulation and distribution of radionuclides in the long-term, uptake into foodstuffs and other exposure pathways.*

— *To investigate a range of potential exposure scenarios and circumstances in order to support arguments for the adequacy of exposure scenarios defined by regulation, or identify alternative or supplementary exposure scenarios.*

317. The IRT observes positive movements by the DOE in this direction as evidenced by the presentations given of the Rev. 1 documents. The Rev. 1 work also addresses a number of points raised in the OCRWM Peer Review of the TSPA-VA [6], which would indicate a wider view of the aims of biosphere assessment.

3.3. THE REGULATORY REQUIREMENTS AND THE FOCUS ON REGULATORY COMPLIANCE

318. The assessment endpoints that the DOE are required to calculate in order to demonstrate compliance are defined by the EPA and NRC proposed rules [3, 4]. It was drawn to the attention of the IRT that there is some discrepancy between the EPA and NRC proposed rules, which have been developed in parallel, and this has caused some uncertainty for the DOE in formulating their documents.

319. The IRT has not carried out a detailed comparison of the rules or attempted to analyze their implications. From an international perspective, the IRT observes that the dose targets should only be considered as ‘reference values’ in the long term, and that the calculated doses should only be considered as indicators of doses that are subject to large uncertainties. These uncertainties are due both to uncertainty in the performance of the engineered and geological barriers and due to decisions in formulating the exposure scenarios that provide the ‘measuring stick’.

320. The IRT considers that either the EPA’s RMEI or the NRC’s more internationally familiar critical group can form a reasonable basis for calculating doses to the hypothetical most exposed individuals or populations in the future, taking account of a range of pathways. The IRT understands the arguments leading to the

somewhat different dose standards of the 0.15 mSv and 0.25 mSv proposed by EPA and NRC, but considers that, following on from comments in the previous paragraph, both are liable to offer an equivalent level of protection. The EPA's 0.04 mSv standard for groundwater protection can be taken as the target for assessing calculated doses due to drinking water only and, hence, is complementary.

321. The IRT concludes that the discrepancies between the EPA and NRC proposed rules cause some semantic difficulty that it would be better to resolve, but should not cause significant problems for the DOE in deciding how to implement a biosphere programme and define a biosphere model for compliance assessment.

322. More significant is the focus of the DOE's biosphere assessment on regulatory compliance. The IRT considers that it is valuable from the perspective of traceable decision making to have a well-defined problem against which to demonstrate regulatory compliance. Formally, it is the duty of the regulators to justify the choice of cases selected for regulatory compliance. *The IRT suggests, however, that it would be prudent for the DOE to satisfy itself that the constraints imposed for compliance assessment do not lead to the neglect of potentially significant uncertainties, processes and interactions that might be considered in a wider context, including a fuller safety assessment. In particular, it cannot be argued that an approach is cautious unless a range of other circumstances and exposure scenarios have been considered and shown to lead to lower calculated doses and or risks.*

323. *The IRT recommends that:*

- *a sufficiently broad examination of possible release pathways and related exposure situations should be examined to identify and justify the more closely-defined case adopted for compliance demonstration, and that*

- *logical extensions of the compliance case and alternative or supplementary situations should be considered to place the case in perspective and to assess the level of bias*[5] *against a broader spectrum of possible cases.*

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[5] Any assessment case will incorporate bias. That is, a model based on the case description will tend to systematically under- or over-estimate impacts relative to the broader spectrum of possibilities that might be considered. Cases selected for regulatory compliance or judging 'safety' will often include a degree of deliberate bias in a cautious or conservative direction so as to overestimate impacts, e.g. by cautious parameter selection or treatment of processes. On the other hand, a model may underestimate if it fails to include a key process leading to exposure or does not consider the location at which highest doses or risks may occur in the long term.

324. The IRT also notes the comments of the TSPA-VA Peer Review Panel (PRP) on the distinction between viability assessment and license application assessment [6]. Whereas the IRT does not necessarily concur with the views expressed by the PRP (which are based on a broader review), the IRT agrees that the objectives for the assessment of both a total system and components of a system should change during the various stages of site characterization, site confirmation and license application. At early stages, the emphasis may be on understanding the physical system and component processes relevant to performance, and developing appropriate models. Whereas, later on, attention may be focused on evaluation by a model aimed specifically at the regulatory requirement.

325. The IRT concludes that the DOE has focused its biosphere assessment too strongly on the regulatory compliance requirement, and considers that the DOE should now step back in order to consider the biosphere more thoroughly as a component of the disposal system from a more scientific stand point.

3.4. INTEGRATION OF THE BIOSPHERE INTO THE TSPA

326. As introduced in Section 3.1, the IRT observes that the DOE biosphere assessment capability has been developed as a relatively recent addition to an existing TSPA capability. In general, when any new component is added to an analysis it is important to examine the interfaces and potential interactions and correlations so that an appropriate method of incorporation and modelling can be devised.

327. By contrast, the DOE's biosphere assessment documentation starts from the premise that the biosphere can be adequately represented by an independent model. Even over the 10,000 year time period, a moderate degree of climate change could lead to temperature, humidity and vegetation changes on Yucca Mountain and in the Amargosa Valley that might be expected to affect both water percolation within the mountain and land use in the valley such that some correlations are introduced. Such correlations are liable to be more marked over longer time scales. It is quite possible that the practical effect of any such correlations or interactions are minor, but a justification that an independent biosphere model can provide an adequate approximation is lacking at present.

328. Similarly, the DOE assessment approach calls for the calculation of concentration-independent BDCFs. *The assumption that BDCFs are concentration-independent is not unreasonable for the trace quantities of radioisotopes that are expected to be released to the biosphere. It is such an important assumption, however, that it would be wise to test the limits of the validity of the assumption. That is, the*

circumstances and radionuclides for which concentration-dependent effects may occur should be identified, and checks made on whether the TSPA results enter into these regions. In addition, it could be important to check the behavior of radionuclides such as C-14 and I-129 since their uptake will depend on background levels of stable carbon and iodine, respectively, and the speciation of the introduced and naturally occurring isotopes in the environment.

329. The IRT observes that the method of selection of radionuclides may provide an example of the difficulties introduced by making a conceptual separation of the biosphere from the other disposal system components. The selection took account of radionuclide inventory radiotoxicity and simple alternative hypothesis for the release and transport of radionuclides from the waste to the biosphere [26]. It did not, however, take account of possible distribution or concentration mechanisms in the biosphere that might lead to changes in relative importance of radionuclides for dose via biosphere pathways. This, together with the undemanding cut-off of only carrying forward nuclides that contribute 95% of the total dose, led to the selection of a somewhat limited set of nuclides focusing on the actinide chains plus just a few other nuclides. Nuclides such as C1-36, Se-79, Nb-94, Pd-107 and Cs-135, all of which have been identified as significant contributors to dose rate in one or several other integrated performance assessments of geological disposal of spent fuel or high-level waste [27; p. 36–37] have all been omitted.

330. Overall, the IRT is concerned by the isolation of the biosphere within the DOE’s TSPA framework and the isolated conceptualization that this engenders. In general, there may be interactions between the biosphere and other system components, and opportunities should be provided to investigate these. It is quite possible that for the characteristics of the Yucca Mountain site and expected release modes these interactions are minor and can be neglected in formulating the TSPA calculational model. Nevertheless, it is still desirable to develop a total system conceptual model in which the biosphere is an integral part.

331. *The IRT recommends that, in future, the consideration of the biosphere is more fully integrated into the total system conceptual model. This is scientifically desirable for the development of the total system model on all timescales, but may have greater potential for practical implications that feed on to the calculation models when considering the total system performance over timescales beyond the 10,000 year time frame. This does not imply that a coupled modelling capacity is required, rather, that the interactions are more fully considered in the system conceptualization and definition of scenarios.*

4. DEFINITION OF THE BIOSPHERE SYSTEM

401. This section provides an evaluation of the completeness and quality of the DOE's biosphere characterization, justification of scenarios and definition of exposed groups and timescales.

4.1. BIOSPHERE CHARACTERIZATION

402. The opening subsection of Section 3.1 of the Biosphere PMR [1] describes the Yucca Mountain and Amargosa Valley region in terms of the location, topography, climate, expected groundwater paths and nearest human habitation and land use. Soil and surficial sediments, local natural vegetation, flora and fauna are not discussed, and although ecosystems are mentioned in the introductory paragraphs as one of the components that form the foundation for long-term representation of the biosphere this is not followed up.

403. The IRT would have expected to see a characterization of the above elements of the biosphere including a discussion of processes that could be relevant to the accumulation, speciation, migration and transfer of radionuclides within and between the various components. Relevant information and factors could include:

- soil types including physical, chemical and organic compositions,
- depth profiles of soil and surficial sediment characteristics,
- local vegetation types, rooting depths, seasonality etc.,
- analysis of mechanisms for radionuclide loss and retention in soils and surficial sediment both sorbed to particulates and in aqueous phases,
- agricultural potential of soils and impacts of long-term cultivation or soil improvement,
- irrigation practice and effects,
- erosion effects on naturally-vegetated and farmed areas,
- disposition of trace minerals, fallout and natural radionuclides in soils as an indicator to the possible behavior of repository-derived radionuclides in the same soils.

404. The IRT concludes that the local biosphere has not been adequately characterized to date or, if it has been, the relevant information has not been used in the biosphere assessment. The IRT observes that the regulations require site-specific consideration based on the present day situation and that the calculation of site-specific BDCFs is stated as an objective of the DOE's biosphere assessment programme. To date, however, this has been interpreted as taking account mainly of site-specific human habits.

405. *The IRT recommends that the DOE should consider a programme of biosphere characterization including on-site measurements, e.g. see above and also Section 5.3. The IRT considers that the examination of site-specific biosphere characteristics and processes, especially related to soil and its potential development, is especially important for the Yucca Mountain Project which is considering an environment unlike most other biosphere environments considered in geological disposal assessment. The information could help assess the applicability to this environment of biosphere data that are available from other sources and otherwise assist in the selection and justification of data.*

4.2. JUSTIFICATION OF THE BIOSPHERE SCENARIOS

406. The Biosphere PMR identifies and evaluates just two exposure scenarios:

— contaminated groundwater extraction and its local domestic and agricultural use;

— the deposition of a contaminated volcanic ash layer on soil and its subsequent agricultural use.

The IRT would have liked to see a description of the possible modes of release of radionuclides from the wastes and into the biosphere. This would place the two analyzed scenarios in perspective. It is possible that the discussion of alternative modes of release and exposure scenarios is covered elsewhere in the TSPA but this was not apparent to the IRT.

407. Examples of other possible release or exposure scenarios that occur to the IRT include:

— the gaseous release of C-14 followed by inhalation or incorporation into vegetation, e.g. in a wetter climate, and subsequent exposure to an individual dwelling on Yucca Mountain;

— the long-term use of groundwater for domestic and commercial purposes and accumulation of radionuclides in waste water courses or sumps, and any subsequent exposure modes;

— the large-scale extraction of groundwater for use further afield from Yucca Mountain;

— the potential for natural discharge of contaminated groundwater at springs or playas, possibly seasonal, that may be used, especially by grazing animals;

— exposure pathways related to the volcanic event during and shortly after its occurrence, as opposed to the consideration of soil contaminated by volcanic ash in the long term;

— the long term leaching of radionuclides from an ash deposit on the mountain and surrounding land to enter local groundwater;

— the exposure of personnel connected with a human intrusion event or due to materials left on site above the repository, as opposed to exposure due to groundwater contamination resulting from an intrusion event.

408. *The IRT suggests that the DOE should identify and evaluate a range of alternative and supplementary biosphere scenarios. In some cases, the scenarios may only require minimal discussion to dismiss as unlikely to occur or unlikely to lead to any significant exposure, but identification and discussion of other possibilities would greatly increase the confidence in the completeness of the DOE's assessment. In other cases, more detailed consideration or calculations may be required to evaluate the pathway. Presentation of such cases, over and above those required to satisfy regulatory requirements, would enrich the overall DOE presentation and safety arguments.*

409. In respect of the first example above, it was mentioned during discussions that doses due to gaseous release at the location of the regulator-defined RMEI or critical group must be trivial. Undoubtedly this is true and even the dose to an individual dwelling on the mountain is likely to be trivial. For completeness, however, it would be desirable to document possible biosphere pathways for gaseous release as part of the biosphere assessment, and to document the estimated exposures as part of the TSPA. This is especially so because the issue of C-14 gaseous release was a factor in the setting aside of the EPA's 40 CFR 191 rule for Yucca Mountain.

410. The IRT observes that the absence of consideration of these ancillary scenarios may be due both to the separation of the biosphere component within the TSPA and

the focus on regulatory requirements already commented on in Sections 3.3 and 3.4. The IRT also recognizes that the DOE is currently making efforts to improve the justification and description of some scenarios, for example, the volcanic event scenario is being improved in response to guidance provided through the NRC Issue Resolution process. Further comments on the volcanic event scenario are given in Section 4.5.

4.3. EXPOSED GROUPS AND INDIVIDUALS

411. The location of the hypothetical RMEI or critical group to be considered in compliance assessment is determined by the EPA and NRC proposed rules. That this single location corresponds to the location where the highest doses are most likely to occur in the long term has not been argued. Even if the regulator takes this burden, it would be helpful for the DOE to present the arguments as to why it is a reasonable and cautious decision to adopt the calculated doses to members of a hypothetical population at this point as a performance indicator.

412. In particular, it is important to establish that the calculated doses are not unduly sensitive to location. In the case of the groundwater release scenario, for example, it is relevant whether the calculated radionuclide concentrations in groundwater change significantly, slightly or not at all, considering different distances ‘downstream’ from the foot of the mountain towards the Amargosa Valley. Section 4.5 considers the volcanic event scenario in this context.

413. The IRT applauds the DOE for its detailed survey of habits and diet of the residents of the Amargosa Valley and other nearby populations. The IRT considers that the exercise is useful:

— Firstly, as illustrating a willingness to engage with the local population, to be aware of actual habits and, therefore, to be better placed to respond to specific concerns of the local population.

— Second, as a guide (only) to the habits that should be considered in regulatory compliance calculations.

Third, if desired, to construct an illustrative case that answers the question “if the radionuclide releases that are projected to occur in the far future were to occurr today, what would be the estimated doses”. This case might be mainly of interest to the local population.

414. *Regarding the diet and habits that should be assigned to a RMEI or critical group for compliance assessment, the IRT considers that the DOE has placed too great a significance on habits determined from the 1997 survey.* Considering the wording of §197.21 of EPA's proposed rule (see Box 4), the IRT considers that accurate projections of future habits are not possible, only generally representative bounds limited by local climate, agricultural productivity and human physiology. Although accurate surveys may fix the present-day (time equal to zero) habits, this may not greatly improve the accuracy of projections for more than a few years into the future. The IRT also notes the EPA statement that "No one should interpret this assumption so literally that only current residences and lifestyles of individuals living in the area on the day of the promulgation of this part can be considered. Rather, we intend that, based on current knowledge, DOE and NRC may use those characteristics in combinations in a cautious but reasonable manner as input into the Yucca Mountain performance projections" (from 40 CFR 197 § III.B.6).

415. *The IRT recommends that it would be prudent for the DOE to consider all human activities that might reasonably and consistently occur and to consider cautious but not extreme dietary intakes and exposure times. The 1997 survey is one input to this consideration and it would be desirable to update the survey so as to augment the available survey information.* To consider only the activities actually occurring at a given date (or even time window) might imply that the assessment must be continually updated to reflect short-term changes in activities. Two examples that illustrate this are:

— the fixing of a low milk intake value on the evidence that, at present, milk produced locally is not consumed in the Valley, and

— the consideration of consumption of locally-produced fish, whereas the catfish farm that was responsible for the assumed supply of local fish is no longer operating.

4.4. TIME FRAMES

416. Based on the EPA proposed rule [3], two time frames are distinguished.

— The period up to 10,000 years after closure, during which a regulatory standard should be met and guidance for the consideration of exposed individuals and the biosphere is given.

— The period after 10,000 years but within the period of geological stability, for which results should be presented up to a dose maximum but no standard applies, and no direct guidance is given.

417. *The IRT recommends that the DOE continues to estimate performance for times beyond the time frame required for regulatory compliance. The DOE should take the opportunity to present assessments that might be more directly comparable with the style of other national assessments, e.g. considering farming communities appropriate to alternative projected future climate conditions. The habits of the indigenous American tribes, as practiced in past times and at different locations, might provide a useful model.*

418. *The IRT suggests that, especially in the longer time frame, the DOE could present a number of complementary performance indicators that are less dependent on the assumptions concerning human habits. These might include a drinking water (only) pathway that would be applicable over a wide range of biosphere conditions, as well as the increase in concentration of radionuclides in the surface environment. The latter might be compared with the level and variability of naturally-occurring radioactivity in the environment, e.g. in terms of total alpha and total beta activity.*

4.5. THE VOLCANIC EVENT SCENARIO

419. In assessing the volcanic event scenario it needs to be stressed that the events represented are both rare and variable. That is, a volcanic event may or may not occur during any period (e.g. during the 10,000 year time frame) and the characterization of the event, if it occurs, is highly uncertain. Thus, the calculated results can only ever be illustrative based on assumptions that are themselves uncertain. These limitations should be kept in mind when presenting and interpreting the results.

420. Regarding the representation of the biosphere for the volcanic event scenario, the IRT observes that no reasoning was presented that the location and habits of the regulatory-defined critical group selected on the basis of a groundwater scenario should also be appropriate for assessing the volcanic event scenario. Consideration of the addition of dose pathways from a groundwater release and a volcanic event is not relevant, since the addition of two pathways can never more than double the risk due to the more important pathway. On the other hand, selection of an inappropriate critical group could lead to an underestimate of dose and risk by many orders of magnitude.

421. Table 3-24 of the PMR indicates that exposure is liable to be dominated by external exposure, resuspension/inhalation and soil ingestion. These exposure modes could be associated with dwelling, recreation and/or ranching and are not necessarily associated with agricultural use of an irrigated soil. Thus, there is no reason to constrain the group to be the same as that considered for the groundwater pathway. Rather, for a given volcanic event, thicker ash deposits and therefore higher concentrations of radionuclides might be expected at locations nearer to the mountain, and this would seem to be a more defensible location for the critical group. Exposures connected to a cinder cone might also be considered, e.g. related to recreational activities.

422. It was stated during the presentations that it is ‘conservatively’ assumed that the wind during a volcanic event blows in southerly direction so as to deposit ash at the location of the regulatory-defined critical group. This is not so much a conservative assumption as a makeshift remedy to fix an otherwise unsatisfactorily constrained case. It was also stated that, in future, a fuller examination of the volcanic event scenario may be undertaken, e.g. including the effect of variability in meteorology during an event.

423. *The IRT recommends that, if a fuller examination of the volcanic event scenario is undertaken, this should include a properly justified selection of the location and habits of the RMEI or critical group (or alternative RMEIs and groups) appropriate to the scenario. The IRT also recommends that, in presenting the TSPA results for this scenario, the stylization of the scenario and the illustrative character of the results should be emphasized.*

5. MODEL DEVELOPMENT, DATA AND RESULTS

501. This section provides an evaluation of the technical analysis of the system including FEP selection, development of conceptual models and their representation in mathematical models and codes, data selection, analysis methods and matters related to quality assurance.

5.1. FEPS AND CONCEPTUAL MODELS

502. The methodology applied by the DOE for the development of conceptual models based on the identification, screening and assembly of relevant features, events and processes (FEPs) is sound and widely used internationally. The method consists of the development of an extensive catalog of potentially-relevant FEPs (possibly assisted by the use of international or other project databases), screening of the FEPs (e.g. based on system-specific relevance, regulatory guidance and potential importance), and assembly into conceptual models of those FEPs considered to be relevant to the assessment. The method has been, apparently, thoroughly applied within other aspects of the DOE's TSPA. At present, however, there appear to be some shortcomings in the application in respect of the biosphere.

503. The IRT observes that the NEA International FEP Database [28] which formed a starting point for the development of a Yucca Mountain-specific FEP database does not include any projects that consider a similar engineered barrier system, geology or biosphere to that considered at Yucca Mountain. In the case of selected aspects of the Yucca Mountain engineered barriers and geology, the DOE carried out specific exercises to expand the consideration to more system-specific aspects. This has not been done in respect of the biosphere as yet.

504. *The IRT recommends that the DOE should consider how best to capture and use the existing scientific and local knowledge regarding the biosphere. For example, the DOE could consider a workshop, or other form of site-specific elicitation of relevant FEPs for the biosphere, in which a range of scientific and local expertise is coordinated. The regulatory guidance should not be considered or used to constrain the scope of any such elicitation. Rather, regulatory guidance should only be used in a subsequent stage of screening if necessary.*

505. The IRT observes that at an early stage the DOE excluded all FEPs related to changes in or alteration of environmental conditions and, also, FEPs related to a potential natural groundwater outfall at Franklin Lake Playa. This was done on the basis of regulatory guidance that demanded focus on present-day arid or semi-arid

conditions and a given location for the critical group. This reduces the potential value of a project FEP database in that it can only be used for the limited purpose of supporting the regulatory model. Information that might help either to justify the regulatory model or consider alternative exposure scenarios or time frames is not recorded or retained.

506. Another important concern of the IRT is the lack of apparent connection between the list of screened FEPs and the conceptual models for the groundwater contamination and volcanic event scenario. In fact, the block diagrams of the biosphere conceptual model (Figs 3-5 and 3-6 of the PMR [1]) seem to owe more to the scope and capabilities of the selected software than the list of screened FEPs; this is discussed further in Section 5.2.

507. *The IRT recommends that the DOE should examine the methods of conceptual model construction described, for example, in the BIOMASS documentation [29] and in national assessment studies, e.g. [30, 31], with a view to devising a method that more clearly tracks the incorporation of individual FEPs into the biosphere model. An alternative approach, that may be valuable, is to audit the biosphere conceptual model as it is represented in the selected software against the list of potentially-relevant FEPs with a view to identifying biases due to omission or simplification.*

508. In respect of the FEP screening process, the IRT observes that regulatory guidance is being used as the reason for exclusion, even when physical impossibility or likelihood within the time frame would be equal or (in the IRT's view) better reasons for exclusion[6]. The IRT observes that in draft Rev.1 documentation, a fuller exploration of FEPs and screening arguments is presented and encourages the DOE to continue with this process. Although exclusion according to regulatory guidance may form a strong argument for compliance calculations and for the regulator as an audience, other audiences may be more convinced by physical and scientific arguments. Presenting all the information, a wider range of FEPs and more thorough scientific evaluation will lead to an assessment that can command respect and acceptance from a wider audience.

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[6] For example, in the Rev.0 documentation consideration of "animal burrowing/intrusion" – a FEP that is present in the NEA FEP Database because of the potential relevance to near-surface disposal facilities and also soil turnover processes – was excluded on the basis that regulatory guidance specified that only biosphere processes at the location of the critical group, and only doses to humans (not to animals) should be considered.

5.2. MATHEMATICAL REPRESENTATION OF THE BIOSPHERE

509. The IRT observes that the biosphere as represented in most repository assessments, including the DOE's assessment for Yucca Mountain, is mathematically relatively simple, usually consisting of a series of linear products, sums and first order coefficients. The main challenges occur in tracking the transfer and disposition of radionuclides (and radionuclide chains) in environments (compartments) which cannot be assumed to be in equilibrium and the very large number of parameters – both nuclide independent and nuclide dependent – that are employed. When choosing a mathematical model to represent specific biosphere and exposure pathways, the main requirement should be sufficient flexibility in definition and parameterization of compartments and transfers such as to accurately represent the conceptual model.

510. The Biosphere PMR describes how the GENII-S computer code [32] was selected on the basis of eight criteria, including a (first) criterion that the code should be acceptable by the regulatory agencies for the purpose of environmental assessment. Examination of this process shows that the selection was performed between seven codes only three of which (MEPAS, GENII and GENII-S) were actually consistent with the groundwater release and soil contamination scenario to be represented. Adding a further requirement to be able to perform stochastic simulation left only the GENII-S code as an option. This does not necessarily imply that the GENII and GENII-S codes are not suitable for representing the Yucca Mountain conceptual biosphere. The IRT considers, however, that by setting a prime criterion that the code should be acceptable by the regulator (indeed, in practice, that the code should already be accepted by the regulator), the DOE removed a significant degree of freedom to investigate alternative, more flexible, biosphere modelling approaches.

511. Examination of the PMR and discussions revealed that the GENII and GENII-S codes have a number of drawbacks. These include the following:

- The biosphere model that GENII incorporates is largely "hard-wired" so that it is difficult to adjust the model to take account of specific circumstances or processes not foreseen in the original model. Thus, for example, ancillary calculations had to be done to investigate the effects of radionuclide loss from the local soil due to erosion, which is not included in the GENII model. There was no potential to investigate the effects of alternative disposition or speciation of radionuclides in the agricultural soil.

- The code only handles a single radionuclide at a time. Thus, apparently, the code is not able to represent radioactive chain decay and ingrowth, so that radionuclide chains must be split into short sections that are assumed to be in equilibrium. Since the code only calculates for one radionuclide at a time, correlated behavior between radionuclides, even of the same chain, cannot be taken into account.

— The code does not allow easy access to intermediate parameters, especially in the GENII-S version. This considerably lessens the value of the code as a tool to investigate biosphere behavior and to understand model response.

512. On the other hand, the IRT was impressed by the awareness that the DOE contractor staff showed of shortcomings of code, the in-depth understanding of biosphere processes, and the effort made to implement the conceptual model despite the drawbacks of the code. The IRT concludes that the staff has done a good job in implementing the conceptual model but has been forced to make a number of lateral judgments, ancillary calculations and checks many of which are not obvious from the documentation.

513. *The IRT recommends that the DOE should consider implementing future biosphere conceptual models using more flexible simulation tools. In practice, relatively few components need to be represented dynamically and for the chronic contamination situations considered in the regulatory scenarios the calculation of crop and animal uptakes and human exposure can generally be done in spreadsheets assuming that equilibrium concentrations are reached.*

514. The IRT appreciates that effort is required to prepare and document the calculation tools so as to be acceptable by the regulator, but considers that the additional flexibility granted would considerably enhance the DOE’s ability to traceably incorporate conceptual models, update models and investigate the impact of specific biosphere processes. *The IRT suggests that, even if the DOE decides to retain the GENII code to calculate impacts for regulatory compliance, additional, more flexible models could be used to investigate aspects of biosphere performance and, also, to assess the potential bias associated with the model represented by the GENII code.*

5.3. DISCUSSION OF PROCESSES AND PARAMETERS

515. The IRT observes that the biosphere includes a very large number of potentially complex processes but, within typical biosphere models for repository assessment, these are generally represented by first order mass transfer coefficients or concentration ratios, e.g. soil K_d values, crop uptake factors, etc. There is consensus that it is appropriate to represent the biosphere in this way for radiological

assessments, and, there are many compilations of the requisite data expressed in the form in which the data can be input directly into a biosphere model such as GENII. The task of judging the suitability of a given data value for use in a specific assessment situation should not be underestimated, however. This requires an understanding of the physical, chemical and/or biological processes that may contribute to the transfer as it is represented in the model, the site-specific conditions that mediate the processes and the conditions under which the candidate data were obtained, and, also, the ability to judge the applicability of the candidate data to the case to be represented.

516. The IRT was impressed by the knowledge displayed by the DOE contractor staff responsible for data selection and setting up the GENII model to represent the conceptual model, and believe that they have done a responsible job within a limited period of time. *The IRT recommends, however, that in future iterations of the biosphere assessment documentation, the consistency of the parameters with the assumptions made in the biosphere model as well as with the site-specific conditions found in Amargosa Valley should be considered and discussed in more detail. This will improve the scientific credibility of the biosphere assessment and, also, allow the DOE to more properly claim that the assessment is indeed site-specific.*

517. The IRT recognizes that there are inherent limitations to obtaining biosphere data that can be considered as fully scientifically founded for several processes. The IRT has specific technical comments on a number processes and/or the associated parameter selection, which are presented in Box 5.

518. On specific points, discussed in Box 5, the IRT suggests that:

— *The K_d approach to modelling the migration of radionuclides in soil should be re-evaluated* having in mind that particle transport in soil may contribute significantly to radionuclide migration in the upper soil layer.

— *The soil characteristics in Amargosa Valley and the problems of application of transfer factors to estimate root uptake*, that were originally determined mainly for soils in temperate environments with other soil types, should be addressed.

— *The sustainability of irrigation assumed for the regulatory scenarios should be discussed* having in mind the possible accumulation of groundwater salts, erosion and actual and potential agricultural practices in the Amargosa Valley.

— *The resuspension and deposition of soil particulates and subsequent doses due to their inhalation should be investigated*, having in mind consistent

Box 5: Technical comments on processes and the associated parameter selection

Radionuclide disposition and migration in soil

Radionuclides will be distributed in various phases in soil and may migrate or be removed from soil by a variety of processes. In GENII the main loss process is assumed to be leaching of radionuclides in an aqueous phase, where the distribution between aqueous and solid phases is determined by a radionuclide-dependent equilibrium distribution coefficient, K_d. Since this is the only parameter to adjust, the leaching rate must be set to represent both aqueous loss and other processes.

Radionuclide migration experiments in the last few years, however, indicate that the migration of radionuclides in the soil is dominated by the migration of radionuclides that are bound to very small particles, and that the sorption/desorption processes contribute only to a minor extent. This observation is especially true for radionuclides that are strongly bound to soil, i.e. those radionuclides with high K_d values.

During particle transport, strongly bound radionuclides such as cesium and the actinides use the same carrier, therefore, the leaching rates of these radionuclides are found to be quite similar [33–36]. However, the leaching rates given in Table 3-7 of the PMR for cesium and actinides cover a range of considerably more than two orders of magnitude. Furthermore, if irrigation water is applied at high rates, see below, this will promote the downward transport of small soil particles and of those radionuclides that are strongly bound to them. Having these processes in mind, the leaching rates applied for Cs, Ac, Th, Pa, Pu, Am appear to be too low, whereas that of Np appears to be too high.

For iodine in soil, a half-life of 1.2 years is assumed. This value seems to be very low, e.g. see [37]. Especially in well-aerated soils that are suitable for irrigation, iodine is strongly bound to the organic matter, which prevents a rapid downward migration.

Derivation of soil-plant transfer factors

The data sources used to provide soil-plant (root uptake) transfer factors derive mainly from experiments performed on soils typical of temperate environments. The uncertainties introduced if these values are applied to the conditions of the Amargosa valley need special consideration. In order to derive appropriate values for soil-plant transfer factors from the literature, it is necessary to characterize the soil properties and to discuss the likely chemical speciation and the possible behavior of the radionuclides to be considered. Possible influencing factors that could be easily determined are, for example, pH-value, redox-potential, soil texture, content of organic matter and the content of nutrients and trace elements.

Although knowledge of these soil parameters does not allow a quantitative assessment of radioecological parameters, their consideration will indicate, at least, trends in behavior and will facilitate the choice of appropriate parameters from the literature. In case of transuranic elements, measurements of radionuclides present in the soil due to weapons testing may be helpful.

Sustainability of irrigation and agriculture practice

The irrigation rates assumed in the groundwater contamination scenario are in the range of 1000–2000 mm/a. Long-term irrigation of soils with groundwater tends to lead to the accumulation of salts in the top soil, which can severely affect the fertility of soils and their agricultural use. It is mentioned in the PMR, that over-watering is practiced in order to prevent an accumulation of salts in the surface soils, which instead accumulate at some depth below the surface. It is also mentioned that agricultural processes such as tilling and grazing may lead to an accelerated erosion rate relative to the adjacent naturally-vegetated areas, leading to a net loss of soil from farmed areas.

The combination of these processes calls into doubt the long-term sustainability of irrigated agriculture on a given plot as assumed in current conceptual models. In practice, various agricultural processes such as crop rotation and soil improvement are used to mitigate irrigation and erosion effects. The likely conclusion is that the assumed scenario of long-term irrigation is conservative, but a more detailed consideration is required to demonstrate that this is the case.

Resuspension, deposition and inhalation doses

The deposition velocity to estimate the re-deposition of resuspended matter appears to be inconsistent with the particle size spectrum for resuspended particles. For the deposition velocity of resuspended particles, a value of 0.001 m/s is assumed. This value appears to be reasonable for particles with diameters around 1 µm. However, resuspended particles typically have diameters of in the range 5 to 10 µm [38]. For those particle sizes, deposition velocities in the order of 0.01 m/s appear to be more appropriate.

This observation also calls into question the calculation of inhalation doses due to resuspended soil particles since the standard dosimetric factors are based on inhalation of 1 µm AMAD (Activity Median Aerodynamic Diameter) aerosols or particulates.

The fact that radionuclides will be preferentially attached to smaller particles within the bulk soil, both due to surface area considerations and also due to the more active sorptive mineral properties of the smaller particles, should be taken into account in calculating the radionuclide concentrations associated with soil resuspension.

All the above issues may be especially critical for the assessment of the volcanic ash deposition scenario. In this scenario, the ash particle size distribution and disposition of radionuclides in the ash must also be considered.

Livestock uptake

The transfer factor from feed to milk for Tc goes back to Ng et al. (1977) [39]. According to more recent investigations, this value appears to be too high by about 2 orders of magnitude. In the IAEA compilation [40] and Johnson et al. [41], an expected value of 2.3×10^{-5} d/l is given. The transfer of Tc to milk is so low, because TcO_4 (pertechnetate) is reduced in the rumen to TcO_2 the absorption of which is quite low. Indications for a very low transfer of Tc to milk are also found in Voigt et al. [42].

Dosimetric data

The DOE is obliged by the proposed regulations to apply the dosimetry of ICRP Publication 30 [43]. The IRT considers that, even if the data are fixed in regulatory compliance calculations, it is important to test the implications of applying more modern dosimetric data such as presented in ICRP Publications 72 and 74 [44, 45]. The IRT observes that ICRP 72 data are adopted in the IAEA Basic Safety Standards [46] and have legal force in EU Member States through implementation of the EURATOM Directive 96/29.

assumptions regarding particle size and the distribution of radionuclides in relation to particle size. This may be especially important for the volcanic ash deposit scenario.

— *The implications of applying more modern dosimetric data should be tested, especially since this data is widely adopted internationally through the IAEA Basic Safety Standards* [46].

5.4. ANALYSIS METHODS AND RESULTS

519. It is difficult to comment on the analysis methods and results for the biosphere because these are best evaluated within the context of the TSPA, which has not been examined by the IRT. The IRT makes the following statements which are based partly on conjecture and ancillary information, and are not definitive.

5.4.1. Biosphere calculations and uncertainty

520. The IRT recognizes the value of probabilistic approaches as means to explore parameter uncertainty (sensitivity analysis) and, also, to incorporate parameter uncertainty into a result (uncertainty analysis). The IRT had difficulty, however, understanding the calculational approach taken by the DOE and its rationale.

521. There are very large uncertainties concerning the future biosphere but these are largely ruled out of consideration in the regulatory scenarios that are analyzed. Within the scenarios analyzed, the IRT understands that the DOE method is as follows:

— to define probability density functions (pdfs) for some input parameters within the GENII model while setting others at fixed values,

— for each radionuclide (and considering different conditions for irrigation) to perform multiple (130) calculations using a latin-hypercube sampling method,

— thus, to provide an empirical distribution of BDCF values for each radionuclide that is fitted by a mathematical distribution (log-normal or shifted log-normal) that is sampled in TSPA calculations.

522. The IRT was initially surprised by the relatively narrow distributions of BDCF values for each radionuclide and, also, the consistency of the geometric standard deviations, indicating a lack of radionuclide dependence in the parametric uncertainty (see Tables 3-17 and 3-20 of the PMR). During the presentations it was confirmed

that the uncertainty introduced by biosphere was small relative to that arising from the EBS and geosphere performance. This can be compared with results from Canadian assessments that included a probabilistic TSPA in which parameters related to the biosphere were sampled [47]. In this case, some biosphere parameters contributed significantly to the total uncertainty, and a back calculation showed that the effective BDCFs could vary between 8 and 12 orders of magnitude for the same radionuclide [48; p. 178].

523. Further examination shows that the small variation in BDCFs in the DOE biosphere assessment apparently arises because, according to the adopted model, the BDCF is dominated by drinking water and leaf interception of irrigation water for most radionuclides, and by fish and/or drinking water for two others. The relevant parameters in the calculation of dose through these pathways are either not sampled or have relatively narrow input distributions. Conversely, input parameters, such as soil-plant uptake factor, that are assigned wide input distributions only figure, presumably, in a few simulations when high parameter values are selected.

524. The IRT considers that the DOE's probabilistic assessment of the biosphere represents only a part of the total uncertainty, even within the confines of the regulatory scenario. The IRT would have preferred to see a more balanced approach in which the uncertainties due to the scenario specification, model choice and parametric uncertainties were all discussed and explored, and the rationale for the selected approach to uncertainty set out. This would include an explanation of the decisions on which uncertainties should be represented by parametric variation, which by other means and which not included.

525. From a methodological point of view, the IRT considers that if the 'measuring stick' is fixed for regulatory compliance (i.e. setting aside the largest portion of the total uncertainty), then it could be regarded as inconsistent to carry the residual variability into the TSPA. Rather, it may be preferable to make deterministic (fixed input parameter) calculations for the regulatory biosphere, and to investigate the uncertainty or bias associated with the fixed value regulatory BDCFs as a separate exercise, see Section 3.2 of this review and references [24, 25].

526. *The IRT suggests that the DOE should re-assess the treatment of uncertainties in the biosphere with regard to the aims of assessment, see Section 3.2, and consider the uncertainties that should be:*

— *represented in the regulatory exposure scenarios within TSPA,*
— *investigated in the regulatory exposure scenarios and model in standalone mode,*
— *explored through alternative models and scenarios.*

In addition, the DOE should discuss more fully the uncertainties due to the scenario specification, model choice and parametric uncertainties, set out the rationale for the selected approach to biosphere uncertainty (both within and outside the regulatory framework) and explain the limitations of the approach and consequent results.

5.4.2. Presentation of total system results

527. The IRT considers that the concept of probability-weighted dose used in presenting TSPA results tends to obscure important aspects of the potential impact. This concept assumes that:

— there is a linear dose-health effect relation over the full range of doses that are considered in all simulations. This is by no means obvious, for example, for the volcanic event scenario, especially if the inhalation and external exposure during and immediately after the event is considered.

— the audience will weigh a high probability, low consequence event as potentially equivalent to a low probability, high consequence event. This is not the case for the majority of audiences.

528. *The IRT suggests that even if probability-weighted dose is the main output required by the regulator, it would be desirable to present disaggregated information (doses and probabilities). This information would more clearly illustrate the nature of the potential impact, so as to better inform decision-makers and other interested audiences. For example, a useful complementary presentation would be the dose profiles conditional on an event occurrence at selected times.*

5.5. QUALITY ASSURANCE, THE USE OF EXPERT JUDGMENT AND VALIDATION

5.5.1. Quality assurance

529. The DOE defines quality assurance as ‘All those planned and systematic actions necessary to provide adequate confidence that an item will perform satisfactorily in service’ [49; Glossary]. In general, the application of a QA system should ensure that work is carried out as intended, e.g. using the approved methods and data, giving confidence that the results are the correct outcome of the stated methods and inputs. This is an essential requirement within an assessment that is to be submitted in support of a license application and, in theory at least, QA may improve the effectiveness of work by promoting an ordered approach and ‘right first time’ application.

530. The IRT did not try to check that all the relevant procedures have been adhered to, but it was clear from the documentation and from staff responses to questions that QA procedures are very rigorously applied within the DOE's assessment work. The IRT was left with the impression that the QA procedures may be onerous and that they may sometimes reduce effectiveness rather than improve it. For example:

— In the case of the GENII and GENII-S computer codes, QA procedures prevent staff from using anything other than compiled code. The purpose of this is to prevent anyone making unauthorized changes to the code, but it also prevents staff from making changes that would help to improve the function and output of the model, for example, to better represent or investigate the conceptual model.

— In the area of data selection, data become 'qualified' when they have been checked off against a series of QA criteria. These focused on objective measures such as the frequency of citing a given data value, whereas in making the data selection the application of expert judgment of a qualified scientist is a more important ingredient (and seemed to have been applied in practice).

531. *The IRT recognizes QA as an essential requirement within an assessment that is to be submitted in support of a license application. The IRT recommends that the DOE examines the existing QA procedures and their application to assessment activities with a view to ensuring the procedures maintain a balance between providing the formal assurance required while not unnecessarily constraining the technical work.*

5.5.2. Expert judgment

532. The EPA proposed rule 40 CFR Part 197 [3; § III.C.2] states that:

> "Expert judgment is typically obtained informally from one or more individuals and is noted by the person(s) seeking the judgment in documentation used to support the activity."

The EPA document goes on to differentiate expert judgment from "expert elicitation … a formal, structured and thoroughly documented process" that is likely to require formal notification to NRC, the presence of independent experts and a meeting in public.

533. These requirements seem to have resulted in the replacement, wherever possible, of expert elicitation by expert judgment, and expert judgment by formalized

procedures. This may be seen from a description of the key elements in the building of the biosphere process model:

- FEP screening – was carried out mainly on the basis of regulatory guidance, see Section 5.1;
- conceptual model construction – was also strongly guided by regulation;
- mathematical model selection – was based on what would be acceptable to the regulator, see Section 5.2;
- data selection – was mostly achieved through 'citation index' approach whose effect was to minimize the need for expert judgment, see above.

534. It was clear, nonetheless, from the presentations made to the IRT that expert judgment has not been eliminated, though its extent is difficult to see in the written material. *The IRT suggests that the use of expert judgment should be made more overt, e.g. through adequately documenting thorough scientific discussions and arguments, and that expert scientific and technical judgments should be used in parallel with the formalized QA criterion approach. The IRT observes that staff quality, and the time to consider and record the necessary scientific and technical judgments, are essential factors in producing a quality assessment.*

5.5.3. Model validation

535. A definition of validation is provided within the DOE 'Analyses and Models' procedure (AP-3-10Q):

> Model validation – a process to determine and document the adequacy of the scientific bases (i.e. confidence) for a model and to demonstrate the model is appropriate and adequate for its intended use.

The procedure further states (AP-3-10Q: Section 5.3) that:

(a) The appropriate level of confidence for a model shall be determined based on the intended use of the model and the importance of the model for assessing post closure system performance …

(b) Existing engineering-type models shall be validated using accepted engineering practices. For all other models, model validation shall consist of comparing

> analysis results against data acquired from the laboratory, field experiments, natural and man-made analogue studies, or other relevant observations. …

This is consistent with the IAEA definition of validation [50]. As an alternative, the DOE procedure allows comparison of analysis results with the results from alternative conceptual models in cases where data are not available to support validation of the model in accordance with the above methods.

536. The DOE's conceptual model of the biosphere incorporates a wide range of processes by which radionuclides can enter the food chain or otherwise result in a potential health detriment. These processes are described by mathematical sub-models incorporated in the GENII-S computer code, as summarized in Appendix C of the PMR. During the discussions on the models, DOE contractor staff stated that comparisons of GENII-S output (the BDCFs) had been made with outputs from other computer models. These comparisons had shown the GENII-S outputs to be consistent with other models, i.e. satisfying the alternative approach to validation allowed by the DOE procedure. The DOE was not able to show, however, how these outputs compare with experimental or other observations.

537. The IRT gained the impression that, in practice, validation is viewed rather more narrowly than is suggested by the 'Analyses and Models' procedure or the IAEA definition. It appears to be seen more as a QA procedure than an exercise in demonstrating confidence through 'ground-truth'. *The IRT suggests that during the more thorough characterization of the biosphere (as recommended in Section 4.1), the DOE should look for opportunities to obtain field data that would enable some degree of model testing, or otherwise support the model. Candidate data could include measurements of trace elements, nuclear fallout or natural radionuclides and their disposition in local soils and plants.*

538. The IRT observes that the term "model validation" must always be used with care. This is because, firstly, models can only be 'valid' or appropriate for their intended use and, secondly, the issue of whether a model is valid or not (i.e. whether an appropriate level of confidence in the model has been achieved) will always involve some degree of subjective judgement.

6. FINAL REMARKS

601. The IRT observes that by commissioning this international peer review of its biosphere assessment programme the DOE has demonstrated a commendable openness and commitment to improving the confidence in future iterations of its TSPA. Furthermore, the IRT is encouraged by the positive movements of the DOE to address various concerns raised, for example, by the TSPA-VA Peer Review and in the IRT's preliminary comments.

602. The IRT appreciates the effort by the DOE and its contractors in preparing and making good quality presentations that satisfactorily addressed the preliminary comments made by the IRT. Requests for supplementary information and documents were swiftly dealt with and all the requested information was received. The visit to Yucca Mountain the Amargosa Valley was well organized and gave the IRT important insights that have contributed to the review.

603. The IRT intends this review as constructive criticism and presents its recommendations and suggestions (summarized at the front of this report) as an aid to the future development of the DOE's biosphere programme based on an international perspective. The IRT acknowledges, however, that the DOE is best placed to determine the value and priority of the recommendations within its specific regulatory and national context. Thus, the decisions to implement changes, or not, and decisions on the relative priority of the recommended developments rest with the DOE.

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APPENDIX I
THE TERMS OF REFERENCE FOR THE REVIEW

Introduction

The US Department of Energy's (the Department) Yucca Mountain Site Characterization Project (YMP) has developed a methodology for assessing the future potential impact of any releases of radionuclides from the Yucca Mountain disposal facility which reach the biosphere. Recognizing that this is a comparatively new and difficult area for predictive assessment, the YMP has requested the International Atomic Energy Agency (IAEA) to organize an independent international expert review of the assessment methodology. The IAEA has accepted with the YMP the request and has agreed the following terms of reference and procedure for conducting the peer review.

Objectives

The objective of this Terms of Reference is to formulate the conditions for the peer review service to be rendered by the IAEA to DOE (YMP). The peer review service will be organized by NSRW in the context of the IAEA's statutory obligation to establish international standards of safety and provide for their application.

The objective of this peer review is to provide, on the basis of available international standards and guidance, an independent assessment of the methodology developed by the US DOE's Yucca Mountain Site Characterization Project. This methodology is reported in the Biosphere Process Model Report (PMR) and associated Analysis and Model Reports (AMRs).

Terms of Reference

The terms of reference for the peer review are:

To review the biosphere assessment methodology being used for the "Total System Performance Assessment" of the Yucca Mountain Deep Disposal facility with the purpose of critically analyzing the proposed rationale and methodology and of identifying consistencies and inconsistencies between methods being used in the frame of the DOE's project and those being established in international standards or practices, for example, in the IAEA's BIOMASS programme.

Framework

The review will be conducted taking account of relevant international standards and practices, and specifically, the requirements put forth by the US Environmental Protection Agency (EPA) and the US Nuclear Regulatory Commission in relation to the assessment of the long term impact of releases of radionuclides to the biosphere from geological repositories.

Content

The review will be primarily based on documents describing the biospheric modelling methodology to be supplied to the IAEA by the Department.

The review will include consideration of:

1. the identification and justification of the conditions and characteristics of the assumed biosphere system;

2. the development of the biosphere conceptual model, including relevant features, events and processes (FEPs);

3. the appropriateness of the GENII-S code for assessing impact;

4. the methodology used to identify the receptor of interest and the behaviour and characteristics of the receptor;

5. the selection and application of biosphere-related parameter values.

Procedure

The review will be conducted by a team of international experts with experience in biosphere assessment modelling in the context of the geological disposal of radioactive wastes. The team members will be selected by the IAEA.

The international review panel will prepare a Peer Review Report that documents the proceeding's findings and recommendations of the review. The Peer Review Report will be delivered to the US Department of Energy.

APPENDIX II
THE INTERNATIONAL REVIEW TEAM

Roger CLARKE (NRPB, United Kingdom) — Group Chairman

Professor Roger Clarke is the Director of the National Radiological Protection Board (NRPB) in the United Kingdom. The NRPB is the focal point in the UK for radiation protection research and advice to the Government, industry and the public. He joined the NRPB in January 1978 as Head of the Nuclear Power Assessments Department, was appointed Secretary in 1983 and became Director in July 1987.

Professor Clarke was educated at the University of Birmingham in England, where he took a degree in physics and then obtained a master degree in reactor physics and technology.

In 1965 he started work at the Berkeley Nuclear Laboratories (BNL) of the then Central Electricity Generating Board and for four years worked on reactor physics research, including optimization of reactor fuel cycles. He then joined the Health Physics Research Section of BNL, where he worked on reactor inventory codes and the establishment of reactor siting and safety codes.

In 1973 Professor Clarke was awarded his PhD from the University of Westminster, London for a thesis on the physical aspects of nuclear reactors in working and public environments. For a number of years he then worked in radiobiology on the implication of non-linear dose-response relationships in radiation carcinogenesis and on the time-dependency of risk.

Professor Clarke has been a member of the International Commission Radiological Protection (ICRP) since 1989, and its Chairman from 1993 until 2001. He is the UK Representative to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and a member of several Advisory Groups to the European Commission. He chaired the Blue Ribbon Panel reviewing the Radiation Effects Research Foundation on behalf of the Japanese and US Governments.

In the UK, Professor Clarke is a member of several UK Advisory Groups, including the Health and Safety Commission's Ionising Radiations Advisory Committee, and the Medical Research Council's Committee on the Effects of Radiation.

Professor Clarke is a Visiting Professor in the Centre for Environmental Technology at Imperial College of Science, Technology and Medicine, University of London, and Visiting Professor in Radiation and Environmental Protection at the University of Surrey. He has been elected an Honorary Fellow of the Royal College of Radiologists, a Fellow of the Royal Society for the encouragement of arts, manufacture and commerce, and is a former president of, and now Honorary Fellow of, the Society for Radiological Protection.

He has published more than 160 papers and reports in the scientific literature and conferences. In recent years he has been the recipient of the G. William Morgan award from the Health Physics Society of the USA, and in the UK the Ellison-Cliffe award from the Royal Society of Medicine.

Pedro CARBONERAS (ENRESA, Spain) — Panel member

Pedro Carboneras has been the Head of the Safety and Licensing Department at the Empresa Nacional de Residuos Radiactivos SA (ENRESA) in Spain since 1986. He is a member of the Spanish Nuclear Society and Vice-President of the Spanish Radiological Protection Society.

Mr. Carboneras is responsible for the ENRESA's environmental restoration projects, the safety assessments of all of ENRESA's projects and in general of the definition and application of radiological safety criteria in radioactive waste management (RWM), along with licensing. He has wide experience in nuclear and radiological safety as well as in RWM in general and particularly in radiological assessments, emergency preparedness and decommissioning of facilities.

Mr. Carboneras obtained a degree in Nuclear Engineering during his attendance at the Polytechnical University of Madrid 1965–1972.

Mr. Carboneras worked as Manager of Production at the Almaraz Nuclear Power Plant (NPP) in Spain 1973–1982, supporting organization, startup and initial operation of the Almaraz NPP (2 × 930 MW). During the period 1982–1985 Mr. Carboneras worked in the Safety and Licensing Department of the Almaraz NPP, helping with the incorporation of “Post-TMI-2” requirements (feed back from experience).

Mr. Carboneras is a member of various standing groups in the IAEA, OECD/NEA and European Commission, specifically: the IAEA-WASSAC Subgroup on “Principles and Criteria as applied for the disposal of RW”, the former NEA-PAAG (Performance Assessment Advisory Group), various EU Groups (management of sealed sources, harmonization of RWM polices, etc.). He has also been member of the ICRP Task Group on radiation protection criteria for the disposal of long-lived solid radioactive waste (Publication ICRP-81).

Over the years, Mr. Carboneras has lectured in waste management courses organized by various Spanish universities. He has also acted as a consultant and/or expert for the IAEA and the European Commission for various projects. He is the author of several papers, lectures and articles in Courses, Conference, Workshops, Seminars and Magazines, both nationally and internationally, generally related to radiological safety as applied in RW Management. Mr. Carboneras is the co-author of technical books and publications related to his areas of expertise.

Ian CROSSLAND (UK Nirex Limited, United Kingdom) — Panel member

Ian Crossland has been working at UK Nirex Limited since 1993. Since 1999 he has been the Strategic Liaison Manager and is responsible for seeking input from academic and international bodies to the company research programmes.

Mr. Crossland studied at the University of Sheffield 1965–1968, where he obtained a B.Met (Hons) in Materials Science. He then went on to obtain a PhD from the Council for National Academic Awards 1968–1971. He is a Fellow of the Institute of Materials (Chartered Engineer) and a member of the British Nuclear Energy Society. He is the principle author and co-author of many papers and publications.

During the period 1968–1993 Mr. Crossland worked for the Central Electricity Generation Board (subsequently Nuclear Electric) as Senior Project Engineer, Group Head and Research Officer on a wide variety of projects relevant to nuclear power generation. During 1993–1999 he was the Research and Development Manager at UK Nirex Limited and was responsible for planning, implementation and reporting of the Nirex Safety Assessment Research Programme, which is the principal UK research programme in the field of deep radioactive waste disposal.

Mr. Crossland is involved in many different projects. Since 1995 he has been active in BIOMASS, an IAEA sponsored international programme on biosphere modelling, acting as Chairman of BIOMASS Theme 1, which deals with biosphere modelling for repository post-closure assessment, since 1998. From 1998 to 2000 he was involved in the EC Concerted Action Project on repository retrievability. He has also acted as a Consultant to the IAEA on many occasions, notably with regards to repository monitoring and quality assurance in R&D.

Carl-Magnus LARSSON (SSI, Sweden) — Panel member

Carl-Magnus Larsson studied chemistry and biology at Stockholm University 1970–1974 and obtained a PhD in Botany in 1980. He has been associate professor in physiological botany since 1984 at Stockholm University and was employed as a research officer/lecturer 1980–1993 at the Department of Botany, also at Stockholm University. He received research funding for fundamental research in plant physiology and biochemistry, and crop science, from the Swedish Natural Science Research Council and the Swedish Research Council for Forestry and Agriculture. He worked as a visiting scientist in laboratories in Germany, Spain and UK.

Mr. Larsson has been employed at the Swedish Radiation Protection Institute (SSI) since September 1993, principally to work on environmental issues. On leave from SSI between January and October 1996 he worked for the National Chemicals Inspectorate, mainly on risk reduction from chemical products, including implementation of EU directives. He returned to SSI in October 1996 to take up the position as Head of the Department for Waste Management and Environmental Protection, which is also his current position. Responsibilities include all public health and environmental protection issues connected to the generation, management and disposal of radioactive waste, including spent nuclear fuel and discharges.

Mr. Larsson is the Co-ordinator of the European Union research project FASSET (Framework for Assessment of Environmental Impact) which involves 14 organizations within six European countries and also the European Commission. He is a member of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency, is a member of the expert group on radioactive waste established under Article 37 of the Euratom Treaty and is a corresponding member of the ICRP Task Group on Environmental Protection.

Gerhard PRÖHL (GSF, Germany) — Panel member

Gerhard Pröhl is Senior Scientist at GSF – National Research Centre for Environment and Health, Institute for Radiation Protection in Neuherberg, Germany, where he has been working since 1981. He is the principle author and co-author of many papers and publications.

Mr. Pröhl studied Agricultural Sciences at the University of Gießen and the Technical University of Munich 1975–1980. In 1990 he obtained a PhD on modelling the transfer of ^{90}Sr, ^{137}Cs and ^{131}I in terrestrial food chains following deposition on agricultural land.

Mr. Pröhl's work and experience cover many different areas, i.e.: development and validation of models for estimating exposures subsequent to accidental releases of radionuclides to the environment for application in national decision support systems of Austria, Germany, Switzerland and Hong Kong (China) and into the EU-system RODOS; development of models for dose assessment including uncertainty analysis for the purpose of long term safety studies of nuclear waste disposals; biosphere modelling and dose assessment for hypothetical reference population groups in the framework of the performance assessment studies for German sites with planned or existing nuclear waste disposals at "Gorleben", "Morsleben", and "Konrad" and "Asse"; site-specific assessment of exposures for the population living in areas of Russia, Belarus and the Ukraine that were contaminated by the Chernobyl accident; and dose reconstruction for the population evacuated from the 30 km zone around the Chernobyl reactor. Member of the committee on "Radiation protection during disposal of radioactive residues and waste" of the German Radiation Protection Commission, 1996–1998.

Hiroyuki UMEKI (JNC, Japan) — Panel member

Hiroyuki Umeki is the General Manager of the Nuclear Cycle Backend Division and is responsible for planning the overall R&D programme for high-level waste disposal, including performance assessment. He began his experience in radioactive waste management at the Power Reactor and Nuclear Fuel Development Corporation (PNC, now JNC) in March 1987. During his time at JNC he has been responsible for the integrated performance assessment of HLW geological disposal in Japan and documented two project reports; the First Progress Report on R&D of HLW disposal (referred to as H3) in 1992 and the Second Progress Report (referred to as H12) in 1999.

Mr. Umeki obtained a BA (in 1977) and an MA (in 1979) from attended the University of Tokyo, both Nuclear Engineering. During the period November 1981 to February 1987, he worked as a research associate of the University of Tokyo (Nuclear Engineering) for research and education in the area of the nuclear fuel cycle, in particular, radioactive waste management, after leaving the PhD program in midcourse. In 1987 he completed his PhD at the University of Tokyo with a thesis on radionuclide transport modelling and uncertainty analysis for the performance assessment of the disposal system.

During 1993–1994 he was a guest researcher at NAGRA in Switzerland (10 months) and participated in the Kristallin-I Project. During 1997–1998 he participated in the OECD/NEA International Peer Review on the Performance Assessment of the US Waste Isolation Pilot Plant (WIPP).

Mr. Umeki has been a member of the OECD/NEA Performance Assessment Advisory Group since 1988 and a member of the Core Group of the OECD/NEA Integration Group for the Safety Case (ISAG) since 2000. He is also a member of the IAEA WASSAC subgroup.

Trevor SUMERLING (Safety Assessment Management Limited, United Kingdom) — Consultant

Trevor Sumerling obtained a 1st class honours degree in physics from Lancaster University in 1975. He then spent 8 years at the UK National Radiological Protection Board (NRPB) where he gained experience in the fields of in vivo monitoring, internal dosimetry and environmental transfer of radionuclides, and became responsible for the in vivo measurement facilities and various field studies at the NRPB. For the past sixteen years he has worked in scientific and engineering consultancies on aspects of radioactive waste disposal assessment and assessment management. In this period, he has contributed significantly to nuclear waste disposal assessment projects in the UK, Switzerland, Sweden, Canada and Japan, and also contributed to international projects and reports. He is Director of Safety Assessment Management Limited, an independent consultancy specializing in radioactive waste disposal assessment.

In the last few years, Mr. Sumerling's work has included: project co-ordination of an independent performance assessment of a potential deep repository development in the UK and review of the proponent's safety documentation on behalf of the UK regulator, as well as contributions to regulatory guidance documentation; assessment methodology development, scenario development and report preparation related to disposal of low/intermediate and high-level waste/spent fuel in various geological environments in Switzerland; an international comparison of disposal concepts and assessment of nuclear fuel wastes as input to the federal review process in Canada; assistance to the UK radioactive waste disposal agency on projects related to co-disposal and waste retrievability.

He has participated in numerous international projects and groups including the NEA 'FEP Database', 'Clay Club' and 'Integrated Performance Assessment Group: Phases 1–3', the NEA RWMC ad hoc Group on Retrievability, the NEA PAAG ad hoc group on Biosphere and the IAEA BIOMASS project. He has participated in, and prepared draft reports related to, the NEA/IAEA international peer review of the USDOE's WIPP 1996 Certification Compliance Assessment and the NEA international peer review of the SKB's SR97 Safety Case.

Carlos TORRES-VIDAL (IAEA) — Scientific Secretary

Mr. Torres-Vidal has 18 years experience as a Nuclear Environmental Scientist with a good background and knowledge of environmental modelling and monitoring, radiation protection and waste safety. Mr. Torres-Vidal was born on 9th of August 1960 in Córdoba, Spain. He was educated at the Polytechnic University of Madrid in Spain, where he became an Industrial Engineer specialist in Nuclear Engineering in 1983.

Carlos Torres-Vidal joined the International Atomic Energy Agency (IAEA) as a Nuclear Environmental Scientist in August 1995. He has been the Head of the Radiation Protection of the Public and the Environment Unit, which is part of the Department of Nuclear Safety, since August 1999. The Unit's main function is the establishment of safety standards for the control of radioactive discharges to the environment. The Unit is engaged in establishing standards for the protection of the environment and in providing advice and guidance on procedures and methods for environmental assessment, modelling and monitoring. The Unit is the focal point for the IAEA's technical interactions with international conventions and treaties concerned with radioactive waste and the environment. Since joining the IAEA in 1995, he has co-ordinated the IAEA project on Biosphere Modelling and Assessment (BIOMASS) and acted as Scientific Secretary of the Co-ordinated Research

Programme on Improvement of Safety Assessment Methodologies for Near Surface Waste Disposal Facilities (ISAM). He has also organized international meetings and prepared technical documents related to environmental modelling and monitoring, safety assessment and waste acceptance criteria for waste disposal facilities. He has managed international projects and organized training events on radiation protection and radioactive waste management in Argentina, Brasil, Chile, Colombia, Cuba, Mexico, Paraguay, Uruguay, Venezuela, eastern European countries and former Soviet Union Republics, in conjunction with the IAEA's Department of Technical Co-operation.

During 1983 he spent a training period in the German company for Reactor Safety (Gesellschaft für Reaktorsicherheit) in Cologne. He gained experience in modelling the behaviour of radioactive isotopes in the environment. In 1984, he started to work at the Department of Nuclear Technology of the Polytechnic University of Madrid. He was a member of the Radiological Consequences Assessment Group for the Probabilistic Safety Assessment of the Spanish Nuclear Power plants. In 1986 he became Radiation Protection Engineer of Unidad Nacional Electrica (UNESA), where he joined radiation protection projects for several Spanish nuclear power plants. During 1988 he was an invited scientist at the Institute of the Environment of the Joint Research Centre of the Commission of the European Community in Ispra, Italy, where he gained experience in safety assessment of radioactive disposal facilities in granite formations. In 1989 he started to work at the Institute for the Environment of the Spanish National Research Centre on Energy, Technology and Environment (CIEMAT). During this time he co-ordinated and implemented national and international projects related to safety assessment of waste disposal practices. He also carried out research projects on the development of methods to analyse and quantify the radiological impact to the biosphere from deep geological disposal facilities for high level radioactive waste.

Mr. Torres-Vidal is member of several advisory groups within the OECD/NEA and IAEA. He has lectured physics and mathematics at the Polytechnic University of Madrid and at courses organized by Spanish and international organizations on waste safety, radiation protection, environmental modelling, monitoring and safety assessment of nuclear power plants and waste disposal facilities.

APPENDIX III
PARTICIPANTS IN THE OPEN SESSIONS OF THE REVIEW

27–28 November 2000, 1 December 2000

PROJECT PARTICIPANTS

Aguilar, R.	Management and Operating Contractor/Sandia National Laboratories
Andrews, B.	Management and Operating Contractor
Bailey, J.	Management and Operating Contractor
Bland, J.	Management and Operating Contractor
Bowlby, B.	Management and Technical Support Contractor
Dyer, R.	Yucca Mountain Site Characterization Office/ United States Department of Energy
Green, R.	Management and Operating Contractor
Hanson, G.	Management and Operating Contractor
Kimble, R.	Management and Operating Contractor
Prince, J.K.	Management and Operating Contractor
Rautenstrauch, K.	Management and Operating Contractor
Rogers, R.	Management and Technical Support Contractor
Schmitt, J.F.	Management and Operating Contractor
Seddon, B.	Atomic Energy of Canada Limited/ United States Department of Energy
Sevougian, S.D.	Management and Operating Contractor
Smistad, E.	Yucca Mountain Site Characterization Office/ United States Department of Energy
Smith, A.J.	Management and Operating Contractor
Swift, P.	Management and Operating Contractor
Tappen, J.	Management and Operating Contractor
Tung, C.H.	Management and Operating Contractor
Tynan, M.	Yucca Mountain Site Characterization Office/ United States Department of Energy

Van Luik, A.	Yucca Mountain Site Characterization Office/ United States Department of Energy
Wasiolek, M.	Management and Operating Contractor
Wikjord, A.	Atomic Energy of Canada Limited/ United States Department of Energy
Wu, W.	Management and Operating Contractor

EXTERNAL PARTICIPANTS

Bechtel, D.A.	Clark County Nuclear Waste Division, United States of America
Frishman, S.	Agency for Nuclear Projects, United States of America
Kessler, J.H.	Electric Power Research Institute, United States of America
Treichel, J.	Nevada Nuclear Waste Task Force, United States of America

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