BIOPROTA

Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management

Update and Review of the IAEA BIOMASS Methodology

Report of the second workshop held in parallel with the first meeting of MODARIA II Working Group 6

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Version 2.0, 14 February 2017

PREFACE

BIOPROTA is an international collaboration forum which seeks to address key uncertainties in the assessment of environmental and human health impacts in the long term arising from release of radionuclides and other contaminants as a result of radioactive waste management practices. It is understood that there are radio-ecological and other data and information issues that are common to specific assessments required in many countries. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and to provide a transparent and traceable basis for the choices of parameter values, as well as for the wider interpretation of information used in assessments. A list of sponsors of BIOPROTA and other information is available at www.bioprota.org.

The general objectives of BIOPROTA are to make available the best sources of information to justify modelling assumptions made within radiological and related assessments of radioactive waste management. Particular emphasis is to be placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities. The programme of activities is driven by assessment needs identified from previous and on-going assessment projects. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions.

This report describes the presentations and discussions during a technical workshop of the BIOPROTA project to review and enhance the IAEA BIOMASS methodology. This was held in parallel with the first Technical Meeting of the IAEA MODARIA II working group 6 (WG6) on 'Biosphere modelling for long-term safety assessments of waste disposal facilities' that was held at the IAEA in Vienna, Austria from 31st October to 3th November 2016. The objectives of WG6 are similar to those of the BIOPROTA project, and the two projects met together to facilitate the sharing of knowledge and experience and to ensure that the parallel work programmes would be beneficial to both, avoiding unnecessary duplication of effort. In addition to the summaries of presentations and discussions, the key areas of enhancement for the methodology were identified and work to be undertaken as part of the BIOPROTA project to address some of the enhancement areas in 2017 is also presented.

Financial support to the BIOPROTA project has been provided by ANDRA, ENSI, NRPA, NUMO, NWMO, Posiva, RWM, SKB and SSM.

Version History

Version 1.0: Draft workshop report prepared by Karen Smith based on participant contributions and reviewed by Graham Smith (GMS Abingdon) and Russell Walke (Quintessa) prior to distribution to meeting participants on 22 December 2016.

Version 2.0: Final workshop report prepared by Karen Smith, taking into account comments received on the draft report. Distributed to workshop participants on 14 February 2017.

CONTENTS

1. INTRODUCTION

An International Atomic Energy Agency (IAEA) report on reference biospheres for solid radioactive waste disposal was published in 2003[a], following extensive international collaborative work within the BIOMASS programme running from 1996 until 2001. The report sets out a structured approach for the assessment of impacts of radionuclide releases to the biosphere from radioactive waste disposal facilities. It also includes examples of the application of the methodology, called Example Reference Biospheres (ERBs), and associated results expressed in terms of radiation dose rates to humans for unit release rates of a sub-set of radionuclides of interest (Nb-94, Tc-99, I-129 and Np-237). With the focus of such assessments being on long-term future biosphere conditions, the methodology was intended to support the development of biosphere models as a measuring instrument, providing assessment results for comparison with protection objectives rather than as a prediction of future conditions and exposures. The BIOMASS work built on initial development of a reference biospheres methodology in the BIOMOVS II collaborative study[b].

The reference biospheres methodology has been used to explicitly or implicitly support a wide range radioactive waste disposal assessments. Understanding gained through these assessments and other inputs has given rise to new knowledge and developments. For example, there have been significant developments in relation to how climate is addressed in long-term assessments and in approaches that allow potential radiation effects on the environment to be explicitly evaluated. There have also been technical developments in models for radionuclide migration and accumulation in different parts of the environment and improved models for assessing doses from the resultant radionuclide concentrations in relevant environmental media, including radionuclide-specific models for C-14, Cl-36 and Se-79, as reported substantially at www.bioprota.org. There have also been significant updates since 2003 in international recommendations on standards for, and methods for assessment of, post-disposal radiological impacts, from the IAEA, the International Commission on Radiological Protection (ICRP) and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA OECD).

Noting all the above, it was considered timely[c] for the reference biospheres methodology to be internationally reviewed and enhanced to take account of this new knowledge and experience. As such, a project has been initiated within the BIOPROTA collaborative forum, supported by a Technical Support Team (TST) comprising Quintessa, GMS Abingdon, RadEcol Consulting, Mike Thorne and Associates and Amphos[21]. A workshop, hosted by FANC in Brussels, Belgium, from 20th to 22nd April 2016 provided a first opportunity to present and discuss experience and suggestions for methodological

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[a] International Atomic Energy Agency (2003). “Reference Biospheres” for Solid Radioactive Waste Disposal: Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (BIOMASS) Programme, IAEA-BIOMASS-6, IAEA, Vienna.

[b] BIOMOVS II (1996). Development of a Reference Biospheres Methodology for Radioactive Waste Disposal. Biospheric Model Validation Study, Phase II Technical Report No. 6, published by the Swedish Radiation Protection Institute, Stockholm, Sweden.

[c] BIOPROTA (2015). Continuing Issues in Biosphere Assessments for Radioactive Waste Management. Report of a workshop held 28 - 29 May 2015, in Madrid, hosted by CIEMAT.

improvements. A report of that workshop has been prepared and is available from the BIOPROTA website (www.bioprota.org). This report provides an overview of presentations and discussions during a second project workshop, held in parallel with the first Technical Meeting of IAEA MODARIA II Working Group 6 (WG6) on 'Biosphere modelling for long-term safety assessments of waste disposal facilities' that has similar interests to that of the BIOPROTA BIOMASS project and with which sharing of progress is likely to be mutually beneficial. It may be noted that the BIORPOTA project is due to complete at the end of 2017, whereas the MODARIA II programme is not due to finish until 2019.

1.1 AIMS AND OBJECTIVES

The overall aim of the BIOPROTA project is to retain the same basic methodological steps set out in the BIOMASS methodology, i.e. not to change the overall approach, but to bring it up-to-date based on new scientific information, experience in assessments and model developments, revised international recommendations and regulatory practice.

The objectives of the first Technical Meeting of MODARIA II WG6 were:

- to draw together international expertise on biosphere assessments for radioactive waste disposal facilities to allow presentation and discussion on the BIOMASS methodology and its application; and,
- to identify the key areas of methodological enhancement required.

1.2 WORKSHOP PARTICIPATION

The first Technical Meeting of the MODARIA II programme was held at the IAEA in Vienna, Austria, from 31 October to 3 November. Working Group 6 (WG6) was attended by 27 participants from 14 countries. Due to parallel working group meetings, not all participants were present throughout the WG6 meetings. Participants are listed in Appendix A.

1.3 REPORT STRUCTURE

Section 2 of this report summarises presentations and associated discussion on experience in the application of the BIOMASS methodology and on new knowledge and experience in biosphere assessments. Section 3 then provides an overview of discussions around the methodological enhancements that may be required. Identified enhancement topics are then summarised in Section 4 with a work programme to address these outlined in Section 5.

2. OVERVIEW OF WG6 PRESENTATIONS AND DISCUSSIONS

The first Technical Meeting of the IAEA MODARIA II programme consisted of joint plenary sessions and separate working group meetings to discuss and develop work programmes. An overview of the plenary session presentations from WG6 and of the working group presentations and discussions on both the original methodology and experience gained from applying the methodology are provided in this section.

2.1 PLENARY PRESENTATION: INTRODUCTION TO WG6 ON BIOSPHERE MODELLING FOR LONG-TERM SAFETY ASSESSMENTS OF RADIOACTIVE WASTE DISPOSAL FACILITIES

Tobias Lindborg presented.

The IAEA has published a number of documents on solid waste disposal, including safety requirements and guides and methodological documents, including the BIOMASS-6 Reference Biospheres methodology that was published in 2003. Since the completion of that methodology, there has been considerable developments in biosphere modelling, including:

- Experience from examples of practical application of the BIOMASS methodology;
- Experience of site characterisation at real sites (e.g. Finland, Sweden, France, Canada, USA, etc.), recognising how site understanding functions as the basis for model development;
- Science developments, including:
  - Understanding of climate change and landscape evolution
  - Ecosystem understanding and representation
  - Methods in toxicology and in assessing the impact of multiple stressors
- Mathematical representation of processes;
- Developing coherent links to the remainder of the safety assessment (e.g. via the Geosphere-Biosphere Interface);
- Special models for special radionuclides, e.g. C-14, Cl-36 and Se-79;
- A wider range of assessment endpoints, such as complementary indicators and those relevant to non-human biota; and
- Regulatory development and experience of assessment review.

The objective of WG6 is to evaluate, update, clarify and, as appropriate, extend the BIOMASS methodology, taking into account the ongoing work being undertaken within BIOPROTA. It is intended that the output of the work programme will be a report that:

- Describes the biosphere assessment strategy and how it links to the overall safety assessment to support transparent evaluation against protection objectives;
- Builds on the biosphere concept and describes the lessons learned since 2001, including from the BIOPROTA program;

- Describes supporting information/models needed for dose modelling;
- Extends consideration to a wider range of geographical environments;
- Assesses the latest science that supports dose modelling and concepts;
- Describes how site understanding functions as a basis for model development;
- Links landscape environmental change to dose modelling;
- Evaluates discharge areas, and how to define areas/volumes of interest corresponding to protection objectives;
- Shows how to analyse and address uncertainties and correlations;
- Examines methods for presenting and communicating results to enhance stakeholder confidence; and
- Provides examples of the application of the enhanced methodology based on actual sites rather than being site-generic.

It is proposed that the scope of activities will extend to all types of solid radioactive waste and both deep and near-surface disposal facilities within a wide range of geographical environments. The programme will take account of on-going work in BIOPROTA, but will provide greater focus on assessments of the first few thousand years post-closure than has previously been the case. Information from legacy sites involving mixtures of contaminated land, old disposal facilities and in situ disposals may also provide relevant input.

2.2 BACKGROUND TO THE BIOMASS METHODOLOGY AND ITS DEVELOPMENT

2.2.1 The need for international cooperation on dose assessment for solid waste repositories

Graham Smith presented.

There are considerable difficulties in long-term dose assessments for radioactive waste disposal facilities that relate to determining the nature of the biosphere when projected releases from the geosphere may possibly occur. The timeframes set by the IAEA and others for demonstration of safety are considerable and developers and operators are obliged to undertake assessments throughout these timeframes. There is a need to demonstrate that any releases that may occur in the future will not exceed pre-defined standards, bearing in mind that the biosphere will itself develop over time through both natural processes and as a result of human activities. Human behaviours, and those of non-human species, may also change in response to a changing environment.

The difficulties in undertaking assessments are not new. Indeed, the original BIOMASS methodology was developed very much to address these difficulties. At the highest level, the basic methodology consists of a linear series of steps that could be followed in a traceable and transparent way. In practice, safety assessments are iterative and interactive. New information for the biosphere arises from experience in undertaking assessments and from the output from other assessment groups, potentially including changing source term information from the rest of the safety assessment. New requirements and regulatory and/or stakeholder interests may also arise, along with developments in science and social contexts. This complicates traceability and transparency without diminishing their importance.

The intention of an ‘international’ reference biospheres methodology was to identify common arguments and issues; avoid unnecessary differences in arbitrary assumptions that could challenge credibility; and address fundamental protection issues whilst acknowledging the scope for local differences. As such, the original BIOMASS-6 work programme sought to identify common ground or consensus on how to justify assumptions for long-term dose assessment. It was however difficult to obtain consensus among the ca. 40 organisations from 20 countries that were involved in the work programme. Nonetheless, a step by step methodology was developed that provided a structured approach to assist in maintaining traceability and transparency in assessments (see Figure 2-1).

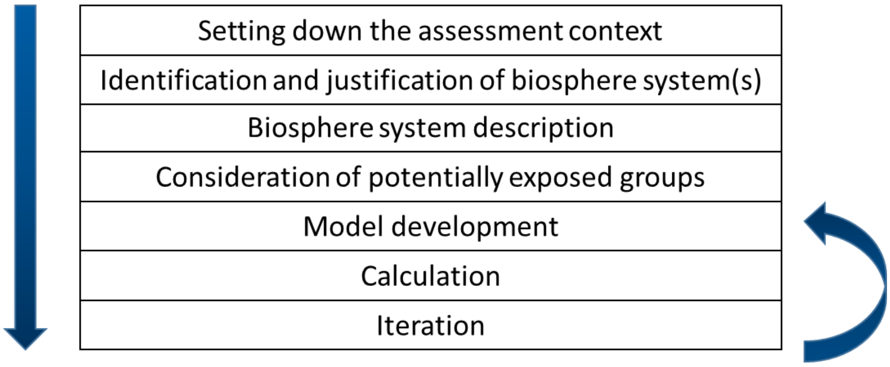

Figure 2-1. The BIOMASS-6 step wise methodology for long-term biosphere assessments.

There have been several international collaboration projects that relate to long-term biosphere assessments since the BIOMASS methodology was published. These include:

- EC BIOCLIM: climate change and implications for modelling, 2004;
- EC BIOMOSA: dose assessment for waste disposal, 2005;
- EMRAS II: dose assessment and environmental change, 2012 (published recently as IAEA TECDOC 1799), including use of analogue sites for environmental change, dose estimation in different climates, dynamic modelling of climate and landscape change, and review of regulatory requirements on addressing environmental change; and,
- IAEA MODARIA: climate and landscape evolution and dose assessment, for which a full draft final report has been completed and provided to the IAEA.

There has also been considerable work undertaken within the BIOPROTA international collaboration that began in 2002 that could provide useful input to the BIOMASS-6 update programme within MODARIA II. Potential inputs include:

- modelling processes at the geosphere-biosphere interface;
- special models for specific radionuclides, e.g. C-14, Cl-36, Se-79;
- practical site characterisation experience;
- use of analogues;

- knowledge quality and long-term dose assessment for non-human biota and compliance with environmental protection objectives;
- human intrusion;
- addressing chemical impacts linked to radioactive waste; and
- output from the current project to review and enhance the BIOMASS methodology, which is due to conclude in December 2017.

Discussion

In addition to the knowledge areas identified above, interest was expressed in the potential for a database of food consumption rates and transfer data. Andra is required to develop a site-specific consumption rate database and knowledge on how this requirement could be addressed for different sites and contexts would be useful. It was noted that, in the UK, local habit surveys are undertaken and the data from these illustrate that data on consumption rates can be considerably different from that in national statistics. Such surveys, for example, allow the behaviour of inland and coastal communities to be distinguished.

2.2.2 Overview of the BIOMASS methodology

Russell Walke presented an overview of the BIOMASS methodology as a starting point for discussions.

The BIOMASS methodology built on work that was done previously in the BIOMOVS II programme that ran from 1991-1996. The BIOMOVS programme included a task to develop reference biospheres along the lines of reference man, but it was concluded that this was not an easily achievable task and that a reference methodology would be a more useful resource. It was furthermore recognised that iteration was extremely important in assessments with the use of a systematic approach supporting a clear audit trail and that there should be encouragement to avoid overcomplicating assessment models, but ensure that they are fit for purpose. Steps to developing conceptual models in a bottom-up type of approach were identified in the BIOMOVS programme, as illustrated in Figure 2-2. The use of systematic steps was aimed at ensuring transparency in assessments.

The recommendation for the reference biosphere methodology to be further developed was taken forward in Theme 1 of the IAEA BIOMASS programme that ran from 1996 to 2001 with the outcome being the ‘BIOMASS methodology’ (Figure 2-3). Six task groups were established to help develop the methodology, each focussing on the top-level steps of the methodology or on supporting guidance. The methodology is illustrated through examples and supported by annexes on specific topics.

The assessment context calls for an upfront declaration of the underlying premises of the calculation (i.e. what is to be done and why) to avoid the assessment being taken out of context. Setting out a clear assessment context also helps guide necessary assumptions and helps to justify the level of model complexity. Aspects to consider in the assessment context include:

- assessment purpose (e.g. demonstrate compliance with regulations, guide research priorities or site selection, proof of concept, etc.);
- assessment endpoints (e.g. individual dose/risk, doses to non-human biota, concentrations and/or fluxes);

- assessment philosophy (i.e. degree of pessimism);
- repository system (depth, geology, waste type, etc.);
- site context (e.g. climate, topography, possible evolution into the future etc.);
- source-term and geosphere-biosphere interface, including interaction of biosphere/ geosphere/ near-field modellers;
- time frames, recognising that uncertainty increases into the future; and
- societal assumptions, including necessary assumptions about future human habits and the basis for those assumptions (e.g. current and historical behaviours).

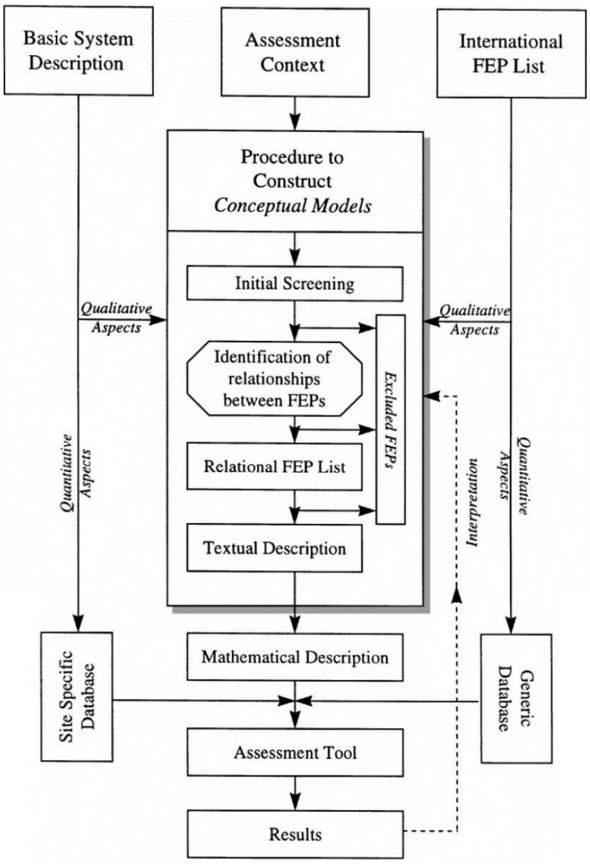

Figure 2-2. Steps in the development of a conceptual model for the biosphere as developed under BIOMOVS II.

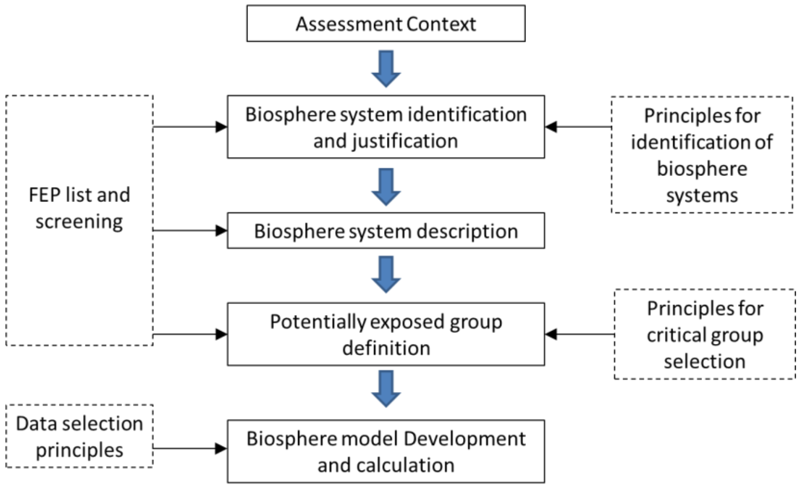

Figure 2-3. The BIOMASS methodology with information flows indicated

The second step is to identify and justify the biosphere system(s) and provide narratives of potential for change into the future. This should include explicit consideration of the geographical extent, location, climate and atmosphere, topography, geology and soils/sediments, water bodies, biota and human communities. Tables of principal components and classifications are provided to help guide selection. It should be noted that regulatory requirements can play an important role in defining the biosphere systems, potentially predefining the system to be considered. A decision tree is provided to support the process of selecting the biosphere system(s). The mechanisms causing the biosphere to change should also be considered and supporting information is again provided for external Features, Events and Processes (FEPs), acting on global to regional/local scales that drive changes such as global climate, seismic events and human actions. The relevance of the different FEPs should be considered in terms of the relevance to the site of interest, taking into account any regulatory requirements.

The third step is then to develop biosphere system descriptions, which are essentially word pictures that provide a qualitative (and where appropriate quantitative) description of the biosphere systems and understanding of the exposure pathways within those systems. The usefulness of interaction matrices in developing understanding of pathways and connectivity was recognised and steps are clearly laid out to support the process and ensure that there is an audit trail of how descriptions have been developed. Inclusion of some quantitative descriptions (e.g. water balance, rates of environmental change etc.) can help guide model development.

Step four is then to consider potentially exposed groups and a series of guiding steps is again provided. These include review of exposure modes and routes, identification of relevant human activities and combining this information to identify those exposure routes and human activities most likely to result in the highest doses. The data requirements for the group habits should then be identified and data selected to support the assessment. It is recognised that it can be difficult to define exposure groups at an early stage of a repository programme since it is unlikely that the areas where the highest radioactivity concentrations will occur will be known until modelling has been performed. It may therefore be appropriate to define a series of exposure groups that can then be refined as the assessment programme progresses.

Model development then comprises step five. Conceptual model objects should be identified from the distinct environmental media potentially influencing doses to exposure groups and interactions between these objects considered, potentially through the use of an interaction matrix. Lists of FEPs are provided that can be used to audit this process and ensure that important processes are not overlooked. Data sources should then be identified and the mathematical model defined, taking into account the available data sources and scientific understanding. The output should be a quantitative model. There will necessarily be iteration and refinement throughout and process / influence diagrams and interaction matrices can be beneficial in guiding model development.

The final step in the methodology is then calculation of the concentrations of radionuclides in environmental media and dose calculations for exposure groups as previously defined and consistent with the assessment context. There was not a lot of discussion in the methodology on the calculation of assessment endpoints or on results communication.

In addition to the step wise methodology, a series of supporting annexes are provided, such as classification schemes, guidance on potential exposure group selection, FEP lists, and the application of data in an assessment. A data protocol to support the choice and use of data in assessment models was also provided. A series of example practical applications was also provided to illustrate the methodology and to explore the feasibility of using generic examples as reference biospheres.

2.3 PRACTICAL EXPERIENCE

2.3.1 Information needed in support of dose assessment, learning from the SKB Forsmark assessments

Tobias Lindborg led discussions.

To undertake a safety assessments for a radioactive waste disposal facility, it is necessary to look at the whole disposal system rather than considering different aspects such as the near-field or the biosphere in isolation. Flow paths from the near-field, through the geosphere and ultimately to the biosphere are continuous and discussion between different assessment groups is therefore required to ensure that discharge pathways are appropriately identified and that assumptions, such as the location of wells, are both appropriate and conceptually correct. In addition to information being discussed on the upward transport of radionuclides, the biosphere assessment team need to provide information on processes such as precipitation and infiltration that can affect groundwater migration of radionuclides. Assumptions throughout the system as a whole must be consistent. This point was not clearly made in the BIOMASS methodology and it will therefore be important to ensure that this is clearly illustrated in the enhanced methodology.

A further aspect that requires greater consideration is the need to consider the stage of the repository programme in relation to the assessment, ensuring that the current needs for the assessment are defined at the start of each stage of assessment. The need to consider the stage of the programme was captured within the assessment context step of the methodology, but the benefit of emphasising this aspect was not recognised. For example, an assessment undertaken without an actual site having been selected and characterised could lead to models being developed that are not appropriate for use when moving to a site-specific context and that provide misleading results when used to address site-specific issues. More general issues around the methodology rather than just the technical aspects should therefore be considered to ensure that the resultant approach is clear and useful, irrespective of the stage of assessment.

The need for validation of assessment models is a further aspect that could be considered in the enhanced methodology, for example whether assessment models could be validated using data from current exposure situations such as legacy sites. There may therefore be merit in WG6 connecting with working group 1 on 'NORM and Nuclear Legacy Sites' to identify whether there are appropriate legacy site scenarios to which long-term biosphere assessment models could be applied in model-model and/or model-data assessment scenario comparisons.

2.3.2 RWM biosphere work

Ray Kowe presented.

Radioactive Waste Management Ltd (RWM) is the implementer for the geological disposal of higher activity radioactive wastes in the UK. No site has been selected for a geological repository and biosphere work to date has therefore been site-generic in nature.

A terrestrial biosphere model has been developed that incorporates various terrestrial system components that could give rise to the potential exposure of people. The model has been kept relatively simple due to the generic nature of the programme to date. The key components and interactions in the model are illustrated in Figure 2-4. A simple marine model component has recently been incorporated into the model (Figure 2-5). The overall assessment model will be further developed and expanded as the disposal programme moves to a site-specific stage.

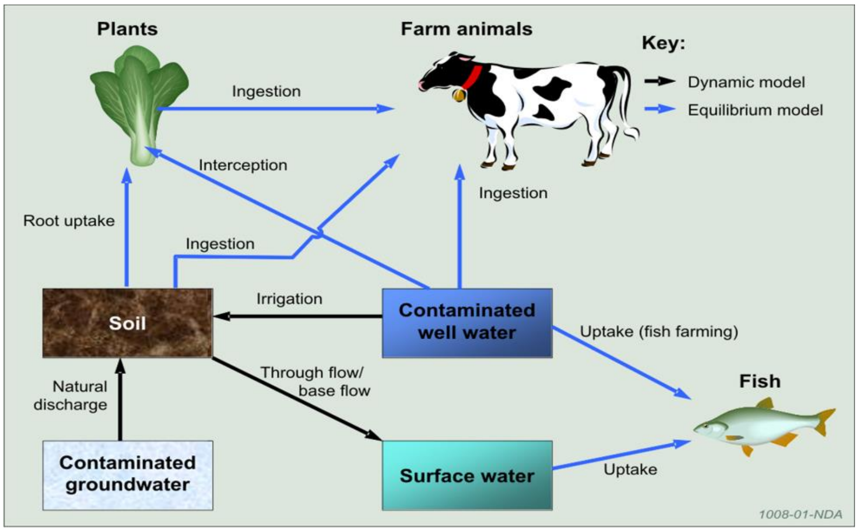

Figure 2-4. Key components and their interactions in the RWM terrestrial model.

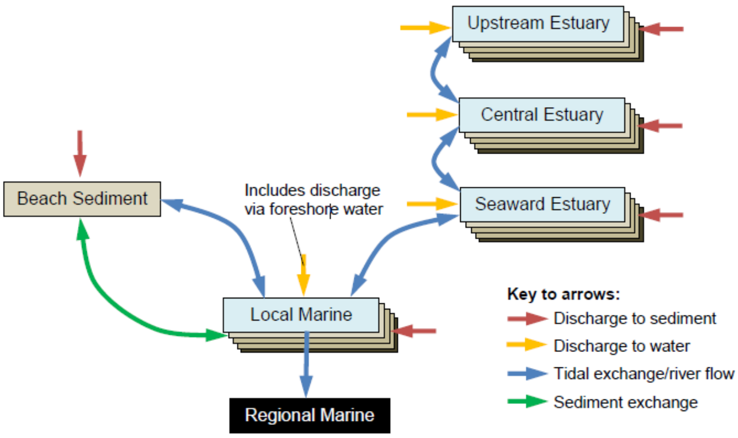

Figure 2-5. Key components and their interactions in the RWM marine model.

Climate-change scenarios considered to date incorporate five climate conditions (boreal, periglacial, glacial, temperate and sub-tropical) over a timeframe of 100,000 years. The potential climate change scenarios were initially based on different fossil fuel emission scenarios from BIOCLIM. However, RWM participated in WG6 of the first MODARIA programme on the development of a common framework for addressing environmental change in long-term safety assessments of radioactive waste disposal facilities, which has taken climate considerations forward. Whether or not specific climate scenarios are needed for the marine model is to be decided.

As a result of the programme of engagement with stakeholders, both public and regulators, 22 issues have been identified that need to be addressed by RWM. Of the 22 identified issues, 16 relate to biota dose assessment. The working groups of the MODARIA programme that focussed on biota dose assessment have therefore been of interest and a watching brief has been kept of the activities of each of these groups. RWM is also part sponsoring the NERC TRansfer-Exposure-Effects (TREE) integrated multi-disciplinary research project looking at the long-term effects of radiation on biota and testing exposure models in the real environment of the Chernobyl exclusion zone (CEZ). Combined laboratory and field studies in the Chernobyl exclusion zone (CEZ) are being undertaken. There are four work packages associated with the research programme:

- WP1 – Soil biogeochemical model parameterisation, aimed at improving the understanding of the biogeochemical behaviour of key radionuclides I-129, Se-79, Tc-99 and U-235/238 in soil to assess if short-term measurements in laboratory experiments can be used to predict the long-term behaviour in soils by testing against CEZ data;
- WP2 – Plant and wildlife REML (Residual Maximum Likelihood) and ionomic models, aimed at investigating whether novel approaches can be used to estimate radionuclide activity concentrations in the human foodchain and in terrestrial and aquatic wildlife;
- WP3 – uncertainty in exposure assessment of wildlife, which aims to evaluate uncertainties in wildlife exposure estimation by assessing how animals utilise contaminated environments; and
- WP4 – Effects mechanisms and transgenerational impacts, which aims to improve the mechanistic understanding of the long-term impacts of chronic radiation exposure in response to the observation that lower exposures are having a greater effect on biota in the CEZ than previously thought.

Throughout the CEZ, 80 sites have been selected and cameras deployed to capture images of wildlife and their behaviour. The animals in the CEZ appear to be thriving, which is due to the absence of people; the first brown bear in 30 years has been sighted and wolf population densities are seven times those in other local regions.

RWM is continuing to have a strong involvement in international work programmes, including supporting several BIOPROTA work programmes such as C-14 model-data inter-comparisons and the project to update the BIOMASS methodology. There are also several future work activities planned, including undertaking a review of SEA and biosphere assessment approaches, considering climate change scenarios for the marine model, and giving consideration to the impact of climate state transitions to evaluate the need for sequential or non-sequential representation of climate change. There is also ongoing work to consider the implications of the EC Groundwater Daughter Directive (GWDD) being transposed into UK legislation and applicable to the geological disposal of radioactive wastes, as well as in other contexts. The GWDD refers to hazardous substances and non-hazardous pollutants. In the UK, some 305 potentially hazardous materials have been identified and have been screened against the waste inventory. At least 49 hazardous materials may be present, including mercury, cadmium from batteries, and organic materials from cleaning products. The description for non-hazardous pollutants is vaguer than that for hazardous substances and no list of substances is currently available. The list could however be extensive, potentially including aspects such as thermal pollution. RWM is currently looking to develop a road map to addressing the issue, which could have implications for the whole disposal system. A stepwise approach to addressing the issue is planned, to include:

- Initial engagement with other waste management organisations on the implications of the GWDD;
- Ongoing engagement with UK regulators to ensure that a common and clear understanding of regulatory expectations is established, and an appropriate assessment framework developed;
- Screening of the UK inventory to identify hazardous substances and non-hazardous pollutants present in the wastes;
- Continued discussions with waste producers on hazardous substances and non-hazardous pollutants present in the wastes; and
- Development of a conceptual model, together with the appropriate data, to calculate the concentrations of non-radiological pollutants at defined compliance points.

Discussion

Some work has already been undertaken by RWM to look at hazardous chemicals in radioactive waste, with beryllium being one of the top six hazardous materials identified in a previous assessment. Calculated inhalation and ingestion intake rates were compared with toxicity standards and tolerable daily intakes. This work was undertaken some time ago and more recent inventory work has been done since. It may therefore be appropriate to revisit this work, but understanding of the appropriate compliance points for hazardous and non-hazardous materials would be needed. For landfill assessments the compliance point is taken as the site boundary, but this may not be so appropriate for a deep geological facility since there are no receptors at the boundary. Further discussion with UK regulators is therefore required.

LLWR has undertaken an assessment of chemical hazards in low level waste disposals for which the US EPA approach was used. Concentrations prior to an aquifer were calculated and immediate dilution coefficients applied from the EPA methodology, with the resultant concentration values were used to compare with standards at the compliance point.

Minimum reporting values (MRV) for chemicals can be important in evaluating hazardous and non-hazardous pollutant impacts and reporting techniques can vary. This could be particularly important with regard to the 'prevent' requirement of the GWDD for hazardous substances, with the potential for effort to be spent to address concerns around substances reported as being at MRV, particularly for substances with an MRV close to human health or environmental protection criteria.

In addition to hazardous and non-hazardous pollutants in radioactive waste, there are requirements on some organisations to consider also hazardous materials associated with engineered barriers and/or excavated materials. Identifying appropriate toxicity standards for compliance demonstration for the range of materials that may be present in waste or engineered barriers can be an issue. Some work has been undertaken on behalf of the IAEA on uranium-series radionuclides, with toxicity criteria for both people and non-human biota being considered The report, which is not yet published, will not provide any recommendations on standards, but will bring to the fore the standards in use nationally and internationally.

There may be merit in considering issues around the GWDD in the enhanced methodology. It would be difficult conceptually to suggest different approaches for radionuclides and other hazardous substances when element transport through the system occurs irrespective of whether a substance is radioactive or not. Use of a consistent methodology should therefore be recommended. Additional aspects that were not included in the original methodology that may merit greater consideration include non-human biota as receptors and the protection of resources. Climate and the representation of processes in moving from the geosphere to the biosphere also require further consideration in the methodology.

2.3.3 Application of the BIOMASS methodology by Andra for long-term safety assessments

Lise Griffault presented.

The BIOMASS methodology has been an important resource for Andra, having been applied in previous safety cases and having been an important input to the development of a regulator-agreed five step strategy for defining and describing the biosphere in safety cases for the disposal of radioactive waste (Figure 2-6).

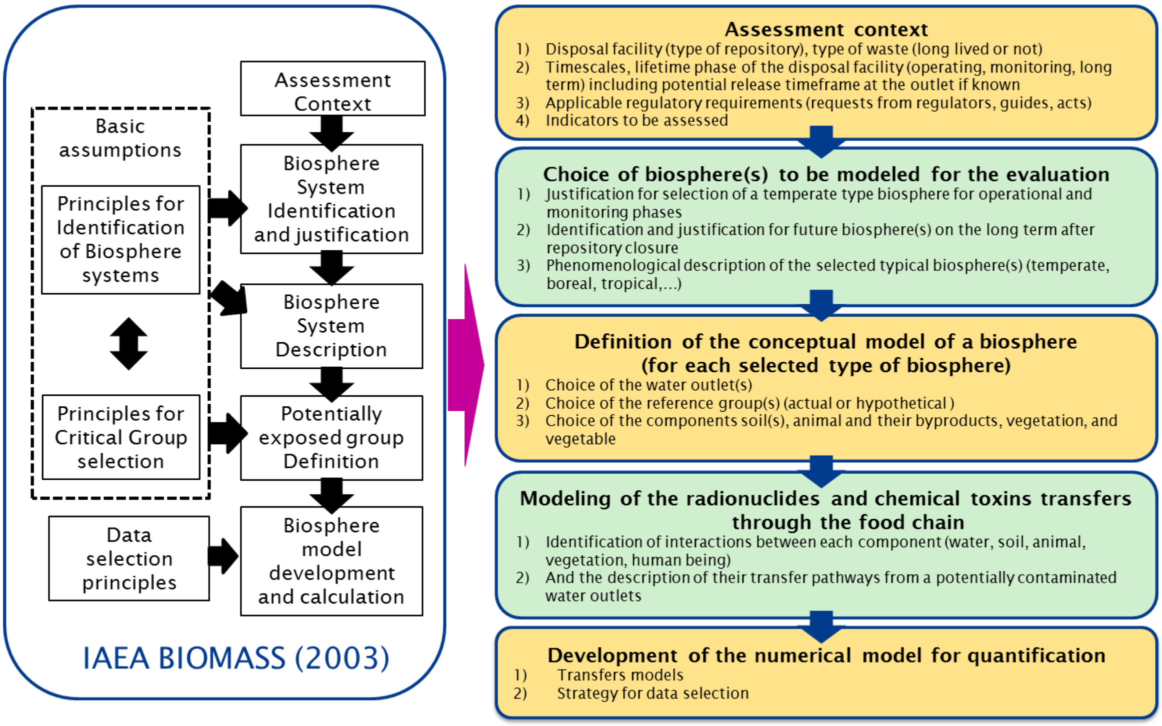

Figure 2-6. Andra's five-step strategy for defining and describing the biosphere (right), developed on the basis of the BIOMASS methodology (left).

The biosphere, which comprises the part of the environment that is easily accessible to human activities and is defined as the global sum of all ecosystems comprising all living beings and the environments in which they live, plays an important role in impact assessments. It has no safety function attributed to it, but is the last step in modelling the transfer of radionuclides and other hazardous substances to people, the principal receptor against which compliance is demonstrated.

The strategy and approach to defining and describing the biosphere was developed on the basis of international practices (i.e. BIOMASS) and through consultation with regulators. The strategy and approach are applicable to both existing surface waste disposal facilities and to long-term geological disposal projects and cover both the operational and post-closure phases. The focus is largely on the transfer of contaminants via water pathways, taking into account the specificity that different sites can bring and drawing upon previous experience from assessments. Intrusion scenarios have not yet been included.

The approach has been applied to the post closure phase of two facilities; the planned Cigéo deep disposal facility for the disposal of HLW and ILW in a sedimentary clay formation at a depth of around 500 m and the operational CSA surface disposal facility for LLW. A feasibility dossier was published for the Cigéo facility in 2005, with a safety option dossier being completed in 2016 (due to be made publicly available in 2017). The safety option dossier for 2016 is required prior to the submission of a safety assessment and sets out the approach that will be taken. A safety report was published for CSA in 2004, and is being re-examined in 2016 with the BIOMASS-based approach being applied and account being taken of climate change.

Regulatory guidelines were issued in 2008 by the French Nuclear Safety Authority that introduced the notion of typical biospheres that are representative of a particular climate state for long-term post-closure safety assessments. Andra's approach to addressing these guidelines has been to describe plausible, and therefore justifiable, typical biospheres for climate conditions that could exist in the future, based on simulations of climatic and geomorphological evolution for two scenarios: 1) natural climate evolution and 2) anthropogenically disturbed climate evolution. For the Cigéo facility, a timeframe of 1 million years post-closure was applied, whereas for the CSA facility, a 10,000 year post-closure assessment period was applied. Climate conditions during these timeframes were derived from BIOCLIM, with the following conclusions:

- A "temperate typical biosphere" may exist at any time scale and for any overall climate change scenario.
- A "cold typical biosphere" is plausible for any climate change scenario, occurring at 50,000 years at the earliest and in the context of a natural evolution of the climate.
- A "Warm typical biosphere" may be envisaged in the case of a perturbed evolution of the climate (accounting for anthropic effects) and may occur relatively early in the post-closure period.

Warm climate biospheres were not considered in the 2005 dossier and this was therefore a new aspect to consider. All plausible biospheres were considered in the 2016 assessment and considered to be equally plausible.

Previously for the CSA surface disposal facility, time steps of 1,000 years had been adopted, but warmer climate conditions could occur within the first 1,000 years. A greater emphasis was therefore placed on evaluating the climate and possible biospheres within the early post-closure phase. Results indicated that, for the next 50 years, temperate climate conditions will prevail with Cr subtropical conditions potentially occurring between 50 and 350 years, followed by Cs subtropical conditions from 350 to 10,000 years from present.

For each climate biosphere (temperate, warm type and cold type), conceptual models have been developed, with each being treated separately, i.e. sequential climates are not considered.

The choice of outlet point for contaminated groundwater was based on hydrogeological modelling and radionuclide transport simulations, taking account of climate change, and for both long and short time scales. There was a certain degree of realism in the modelling undertaken. For example, the maximum sustainable yield of water, flow rates, dilution and usage were considered along with the characteristics of radionuclide transport in both time and space. Efforts were also made to try to ensure that water resources were compatible with the assumed human activity requirements, such as irrigation of crops or use as drinking water. Outlets such as rivers and deep wells have not yet been considered, but are under discussion with the regulators.

In choosing the hypothetical reference group or groups, behaviours representative of the habits of local groups and resources available in 'typical biospheres' within a regional context for the different climates were considered. Multiple exposure pathways were taken into account for different activities and exposure pathways arising from multiple activities were permitted, as appropriate. The water outlet was an important factor with availability and usage being important considerations. Food habits of people inhabiting the local area were used for the temperate biosphere and discussions with the regulator are ongoing with regard to the development of a database of local habit data. For warmer sub-tropical and colder climates, international analogue results are to be used, such as Spain as an analogue for a warmer climate and Sweden or Finland for a colder climate. The analogue sites and data are currently under discussion.

The BIOMASS methodology provided tables of potentially exposed groups along with details of activities leading to potential exposures. This provided a very useful and efficient basis for exploring potential transfer pathways to humans by considering either multiple exposures in relation to average behaviour or specific exposure pathways relating to a particular behaviour. The methodology was less clear when it came to guidance on the selection of data for assessment.

For exposure groups with multiple activities, the arithmetic mean of habit data was adopted and sensitivities to those data were considered. The regulator expressed a desire for pessimistic assumptions regarding food consumption, but these were considered unrealistic as they would result in excessive food intake. However, to address regulatory concerns, the 95th percentile (or mean + 2 standard deviations) was adopted for the three food groups contributing the most to the group exposure with the arithmetic mean being applied to all others.

A compartmental transfer model is applied for the majority of radionuclides to evaluate exposure of groups under the different climates, with specific activity models being used for Cl-36, H-3 and C-14. No major differences in exposure have been noted between warm and temperate climates, with doses being within 1 order of magnitude.

From the application of the methodology it has been possible to identify the most important parameters having a strong influence on impact of releases.

- The outlet is very important in defining the potentially exposed group and a good understanding of the potential for dilution at the outlet is needed to evaluate exposure.
- Food consumption habits and level of self-sufficiency are important parameters.
- Stable isotope concentrations are very important parameters for specific activity models.

The overall models and software applied are also very important.

Data collection and treatment is a very important aspect of assessments, supporting both evaluation of radionuclide transport and biosphere evolution over time. Site characterisation and surveys are very important in gathering data to support assumptions around the behaviour of potentially exposed groups, and further guidance on methods for data acquisition from site characterisation programmes, including characterisation of other sites for analogue climate conditions, would be beneficial.

Application of the BIOMASS methodology to define the biosphere was accepted by the regulators and proved to be useful for both operational and post-closure phases. During the operational phase, the assessment was based on actual activities of people in the local area, whereas for the post-closure phase, the water resource characteristics of the outlet were the governing factor, with a cautious approach applied to evaluate exposure. Landscape modelling is therefore very important for post-closure assessments, enabling outlet points to be identified.

Based on the experience gained in applying the methodology, a number of items have been identified that would benefit from further development / enhancement:

- Further analysis of ‘snap-shot’ climate biospheres versus sequential climate biospheres, including transitional phases.

- Greater consideration of erosion as a mechanism for landscape evolution and radionuclide transport.
- Data acquisition guidance, including what to do to acquire data for pathways of exposure that are not currently in existence at a site, but that could occur in the future (e.g. the presence of rivers) and survey methods for gathering local habit data.
- Evaluating radionuclide transport across the interface of the geosphere and biosphere, which is a great source of uncertainty in assessments.
- Greater information on the choice of software / models for assessments and on updating these as assessment programmes progress.
- Addressing uncertainties in transfer parameters such as foliar and root transfer to fruit, radionuclide transfer parameters in natural and semi-natural ecosystems, and atmospheric dispersion of activity from terrestrial to aquatic ecosystems from erosional processes (e.g. resuspension).
- Identifying differences in the philosophical approach to assessments depending upon whether assessing operational or post-closure phases.
- How to include probabilistic analyses in assessments.
- How to address alternative safety criteria, such as the need to address chemical hazards (what reference values / safety criteria should be applied) and how to benchmark and rank hazards from chemicals and radionuclides and also the approaches, models and data that can be used to evaluate doses to non-human biota.

Discussion

Whilst it was required that, for the CSA surface disposal facility, a timeframe of 10,000 years should be assessed, Andra continued the assessment out to 50,000 years. The facility is for short-lived radionuclides, but some longer lived radionuclides such as Cl-36 are present at limited levels. The assessment was therefore undertaken until these longer-lived radionuclides were projected to be released to the biosphere outlet point(s).

In addition to surface disposal, there is a plan to undertake sub-surface disposal, which may affect landscape evolution, with erosion being a process that will be of particular interest.

2.4 USING THE BIOMASS METHODOLOGY IN SR-SITE

Ulrik Kautsky presented.

An application to build a repository for spent nuclear fuel was submitted by SKB to the regulator, SSM, in March 2010. The application, SR-Site, has been reviewed and questions received from SSM have been addressed. A hearing is due to take place in spring 2017 with the Environmental Court, which requires additional considerations to those covered in SR-Site, such as impacts from nitrogen arising from blasting and chemotoxic effects of elements such as uranium. it is hoped a final decision will be made in 2017.

The BIOMASS methodology provides a defined sequential approach to undertaking assessments. In the early phases of assessment for the repository there was some concern expressed that the

BIOMASS methodology had not been explicitly followed at each stage. This was not the case however. The methodology was followed but its use may not have been explicitly stated. The assessment process had been developing over time and, hence, some aspects of the methodology had been undertaken previously, such as defining the assessment context, and therefore were not necessarily documented at each subsequent assessment stage. Iteration was required throughout since, in practice, there is a need to work through different stages in parallel to meet both budget and time constraints. For example, model development and biosphere system descriptions proceeded in parallel with descriptions being developed in detail once release locations had been identified from modelling studies. Lessons learned with regard to managing the assessment process may be valuable aspects to include in an enhanced methodology. From the experience gained in undertaking the assessment it is clear that project constraints and leadership are very important, as is acceptance throughout the assessment team that the biosphere is an important aspect of the assessment, a reality that becomes clearer the closer exposure estimates approach constraints.

For the assessment context, the regulatory requirements for the SR-Site assessment were very clear in terms of risk limits, but there was still some flexibility with regard to compliance demonstration, i.e. the requirements were not prescriptive in how the assessment should be undertaken. In terms of assessment philosophy, the intent was to be as realistic as possible. To support biosphere description, a detailed site characterisation programme was undertaken, resulting in 10 years of site data being available as input to the assessment. This also ensured that the data were consistent, which can be an issue with generic data collations derived from a range of different sites and environmental / climate conditions. The site characterisation programme also ensured that a detailed understanding of the site was developed that in turn supported site modelling. The data, site description and the skills and knowledge base of staff and consultants were also valuable input to subsequent assessments for SFR and SFL and will continue to be invaluable assets in undertaking the required 10-yearly renewal of the safety assessments. The data have also been of value to other assessment groups, for example through providing analogue data for different climate states.

The understanding of the site, developed through the site characterisation programme, was an important input to the identification of potential discharge points that, in turn, allowed the types of biospheres that could be affected to be identified and described and the most exposed group(s) identified. FEP lists were also used throughout the process, but were not considered to be overly helpful in this instance since such a detailed understanding of the system had already been developed. FEP lists were however considered to be a useful resource for earlier stages of assessments.

A focussed meeting was organised to complete interaction matrices during the assessment programme with matrices being developed for each ecosystem and for different climate types. This proved very useful in developing a common understanding of the systems across the assessment team, but was a difficult task since circular rather than linear relationships were evident between the different FEPs, for example, animals can interact with themselves and representing such interactions can be very complicated. The exercise was useful input to the site investigation process however and a learning point was that all elements of the approach need to be well defined to avoid different interpretations throughout the assessment team. Describing the different elements of the approach also helps to identify what it is you are trying to understand.

The evaluation of potential human exposure in SR-Site was based around the calorific requirements of people (equivalent to 110 kg carbon / year) rather than the intake of different produce, allowing the total productivity of the area utilised by people to be considered irrespective of future human consumption habits and allowing the ability of a biosphere object to sustain people to be evaluated. Productivity of a biosphere object could therefore be coupled to food intake and, thus, the population that could be sustained in different areas could be identified. The assumption behind the approach is that persons living, drinking and eating food within the area will be the most exposed, and that the most exposed population is constrained by the productivity of the area. This approach has however been criticised, since it does not represent the necessary variety in human consumption and the approach has therefore been adapted to be more realistic in terms of dietary requirements, e.g. through the use of different habit assumptions, such as a hunter-gatherer in natural ecosystems and different agricultural lifestyles.

The way in which the ‘story’ of human behaviour assumptions, such as the use of simple (primitive) farming practices from those currently available, is communicated to the public should be given consideration. For the SR-Site assessment, there was discussion with SSM on food production assumptions for the assessment that helped guide the approach taken. An argument for the use of simple farming practices was that, where more industrial agricultural practices were employed, these would occur outwith the areas of the landscape that were most likely to receive groundwater discharge and, hence, radionuclide contamination, such as mires. This would lead to greater dilution of radionuclides across the farmed area and result in a lower dose being calculated.

In terms of biosphere modelling, there were a number of supporting models that were used to provide parameters as input the assessment model. Many of these were highly complex and yet may only produce a few parameters for the assessment. Examples include shoreline displacement and surface hydrology models. Version management of models as they develop through the assessment process is very important and Subversion, a file version handling system, was employed by SKB.

The assessment model was developed using Ecolego, which was a useful tool that is compatible with interaction matrices. It was used to derive landscape dose factors (LDF), with the maximum LDF across space and time being selected for dose evaluation. It is only when calculations are completed that it can be determined as to whether the output makes sense or whether there are issues with models and/or parameters that need to be addressed. Model testing and iteration are therefore very important and, from experience, it is considered important to run calculations as soon as possible, rather than waiting for a data freeze, to identify important features and processes that need further consideration. Early model runs can also help to guide site characterisation. It is also important to note that it is not simply a case of re-running models and updating reports as assessments progress. The experience and knowledge can be applied over and over, but the complexity of assessments changes throughout and it may be necessary to go back and review processes and reconsider how to represent these. Different radionuclides may also be identified that need to be incorporated and improved / new data may be available. It is also important to note that discharge areas are only defined once some models have been run, which is contrary to the stepwise process of BIOMASS-6, although reiteration is noted throughout the methodology.

Discussion

One approach to addressing circularity issues in interaction matrices would be to give off-diagonal elements numbers that link to a table where more detailed descriptions can be provided. Influence diagrams may also be useful.

The assessment context should stipulate the need to make links to previous iterations of assessments to ensure that previous decisions are transparent in later iterations and that the results and learning from previous assessments have been carried forward. This is an important aspect to describing why assessments are being undertaken in a particular way as knowledge and experience develop. The use of simple test cases at an early stage in programmes can be useful in providing discussion points with regulators and other stakeholders that can help to guide the assessment programme as it develops.

The ICRP has recommended[d] that, for long-term assessments for solid waste disposal, only adults should be the subject of dose evaluation. ICRP is well aware that doses to children and infants can be higher than those to adults, depending on the biosphere system and radionuclides of interest[e]; nevertheless, the original advice has been confirmed in more recent advice on geological disposal[f]. In any case, it was suggested that children and infants are not automatically ruled out of assessments, particularly for child or infant related exposure pathways such as incidental consumption of soil.

2.5 LLWR PLANNED WORK TOWARDS THE NEXT MAJOR ENVIRONMENTAL SAFETY CASE

Alex Proverbio presented.

The Low Level Waste Repository (LLWR) is the operational national facility for the disposal of LLW in the UK, located near the coast in northwest Cumbria. Disposals began in 1959 and are expected to end around 2130. Prior to being the LLWR, the site was the location of a Royal Ordnance Factory for the production of TNT during World War 2. As a result, there is legacy contamination at the site of both TNT and asbestos.

The first disposals of LLW at the site involved tumble tipping the waste into seven clay-lined trenches. This practice continued until 1995 when there was a move to disposal in concrete engineered vaults, the first of which became operational in 1988. In 1995, a compaction facility for waste became operational at Sellafield and the Drigg Grouting Facility also began operation, allowing the super-compaction of wastes and voidage filling with grout. Vault 9 has recently been made operational (in 2016) for disposals, following from its use for storage of waste since 2010. The current (2016) status is therefore that there are 7 filled trenches that have been covered and two vaults (8 and 9) that are uncovered. Vault 8 is nearing capacity and is therefore being capped. The site layout is illustrated in Figure 2-7.

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[d] "It is then reasonable to calculate the annual dose/risk averaged over the lifetime of the individuals, which means that it is not necessary to calculate doses to different age groups; this average can be adequately represented by the annual dose/ risk to an adult." Para 46 of ICRP (1998). Radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste. ICRP Publication 81. Ann. ICRP 28 (4).

[e] "It is evident {…} that, with the exception of the actinides, the differences among dose to different age groups are generally small (generally less than a factor of 3) in comparison with uncertainties typically found in assessment of dose to the public.". Para 80 of ICRP Publication 101. Without further reference to the recommendation in Publication 81, this is followed in Para 81 by the recommendation, "Therefore, for the purpose of compliance with the dose constraint for continuing exposure, the Commission recommends that the annual dose for the representative person should be defined by three age categories. These categories are 0–5 years (infant), 6–15 years (child), and 16–70 years (adult)." ICRP (2005) Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public. ICRP Publication 101, Ann. ICRP 36 (3), 2006.

[f] In the case of geological disposal, any exposures are expected to occur in the distant future, and to be associated with levels of radionuclides in the environment that change slowly over the time scale of a human life time. Given the inherent uncertainties in calculations extending to the distant future, the dose or risk to an adult representative person will adequately represent the exposure of a person representative of the more highly exposed individuals in the population." Para 95 of ICRP, 2013. Radiological protection in geological disposal of long-lived solid radioactive waste. ICRP Publication 122. Ann. ICRP 42(3).'

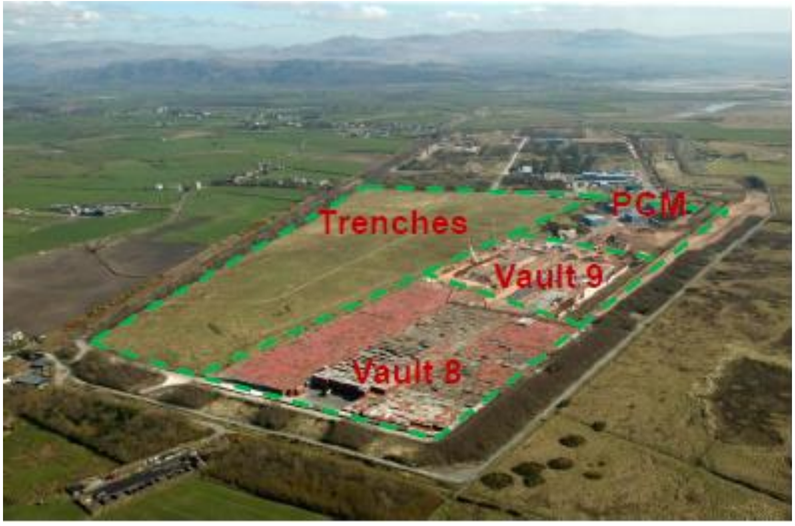

Figure 2-7. LLWR site layout.

There is radon emanating from the disposal trenches and studies have taken place to develop a radiation disposal map of the trench area. Waste Acceptance Criteria (WAC) have also been developed to ensure that disposals are controlled and records maintained, and work is ongoing to address plutonium contaminated magazines (PCM) that are present on the site (see Figure 2-7). Work is also progressing with regard to optimisation of the site and the way in which it is developed into the future. There have been various meetings with the engineering team and programmes undertaken to improve both the radionuclide and non-radionuclide inventories and to continue both groundwater and air monitoring activities.

In 2011, an environmental safety case (ESC) was submitted to the Environment Agency. This was found to be adequate to support an application for a revised Environmental Permit to manage the repository in accordance with the ESC. The permit application was submitted in 2013 and the revised Environmental Permit was received in November 2016. A planning application for disposals in Vault 9 and the construction of Vaults 10 and 11 was granted in July 2016. A major review of the ESC is due to be submitted 2021 and work is underway with a technical development plan having recently been published[g] and agreed with the regulator. The development plan addresses three major areas of safety case approach, development and assessment, and management requirements and design. In total there are 226 activities to be undertaken, including addressing forward issues and comments raised by the regulator on the 2011 ESC.

As a result of collaborative work programmes within BIOPROTA and elsewhere (e.g. with RWM), the LLWR model for the assessment of the impact from C-14 bearing gases was updated both with regard to the near field and for soil-plant transfer in the biosphere. The soil-plant model was revised for processes in the plant canopy atmosphere, such as the transport of carbon dioxide, and for processes

[g] LLWR Environmental Safety Case: Technical Development Plan for the 2021 Environmental Safety Case, LLWR/ESC/R(16)10075, March 2016. Available from http://llwrsite.com/national-repository/esc-permit-approval/.

occurring in the soil. The model considers fluxes of C-14 to the soil root zone, transfer through the root zone and canopy to the atmosphere, plant uptake in the above-ground canopy and direct uptake by plants from the root zone. The update was significant in improving the quality of the model and in demonstrating site compliance with national regulations.

The 2021 ESC is a major ongoing work programme for LLWR. From the safety case approach, there is a need to review FEPs and uncertainties and develop independent safety arguments and to manage and control assessment data. The presentation of the ESC also needs to be addressed with comment having been received on the 2011 ESC that the three reporting levels used proved complicated. Alternative approaches to documentation and provision of summaries are therefore being investigated.

In terms of inventory and the near field, assessment cases need to be defined and the approach to handling uncertainty established. There remain uncertainties in the waste inventory, particularly with regard to spatial variability. Disposals equating to around 800 containers per year are expected at the site, but currently there are of the order of 200 per year. Whenever possible, wastes are diverted elsewhere, for example to incineration, or are super-compacted prior to emplacement in the vaults.

For assessments for the 2021 ESC, a watching brief is being kept on coastal erosion and environmental change science to ensure that the state of the art in knowledge and tools are being employed. Potential exposure groups also require updating along with habits data, based on the behaviour of the current local population in the vicinity of the site. Additional programmes will consider how to undertake more probabilistic calculations, produce an assessment manual and assessment maps that will provide a graphical interface of the connections between the different elements of the assessment. There is also a need to integrate groundwater assessments for the period of authorisation and post-closure, which are currently considered separately. It is intended that both will be linked within a single model.

Discussion

Some of the main issues remaining in terms of the 2021 ESC relate to erosion and sea-level change. The site is currently between 14 and 25 m OD, but the facility is located close to an erosional coastline. The current belief is that coastal erosion will result in the facility being undercut and that vaults will progressively drop. There are however alternative possibilities. As such, a number of different long-term scenarios are being considered, including the use of barriers to prevent erosion of the site. The degree and style of coastal erosion is not determined only by processes associated with global sea level change, regional changes are also of importance, as are the kinetics of change over time, which are very uncertain and will vary according to the ice dynamics of the Greenland and Antarctic ice sheets.

Assuming there are no barriers put in place to prevent erosion from occurring, waste from the facility will eventually be present in the coastal environment. The focus of the BIOMASS methodology was on terrestrial environments and, whilst the principles of the methodology are applicable to coastal environments, there has not been the same level of scrutiny. This is an aspect that could be addressed in the revision to ensure that tables and lists are inclusive of such environments. There may also be merit in adding non-human biota and non-radionuclide assessment aspects, and covering the operational period. A strategic goal for the update should be agreed upon that can guide what should and should not be incorporated.

2.6 DISCHARGE ROUTES AND EXPOSURE PATHWAYS AT YUCCA MOUNTAIN

Mike Thorne presented.

Regulatory requirements for Yucca Mountain set out a very prescriptive biosphere system. The critical exposure group was not located close to the repository, but was rather some 18 km away in the Armargosa township. The reasonably maximally exposed individual was required to be a 'typical' member of this township.

The Yucca Mountain landscape is geologically very young, and is volcanic in origin. Drainage of water through the repository was assumed to occur to the south with the concept for radionuclide migration being that radionuclides would flow downward from the repository, through unsaturated Volcanic Tuff and into the saturated zone where they would be transported south to where the groundwater naturally moves toward the surface (Figure 2-8). Judgement was required as to where a well could be reasonably sunk and this was taken to be the location of the maximally exposed individual (RMEI). Potential locations for wells are however debatable, depending upon the water requirements of a community. In practice, the location of the well was based around the convergence point of radionuclide transport paths through the saturated zone (Figure 2-9).

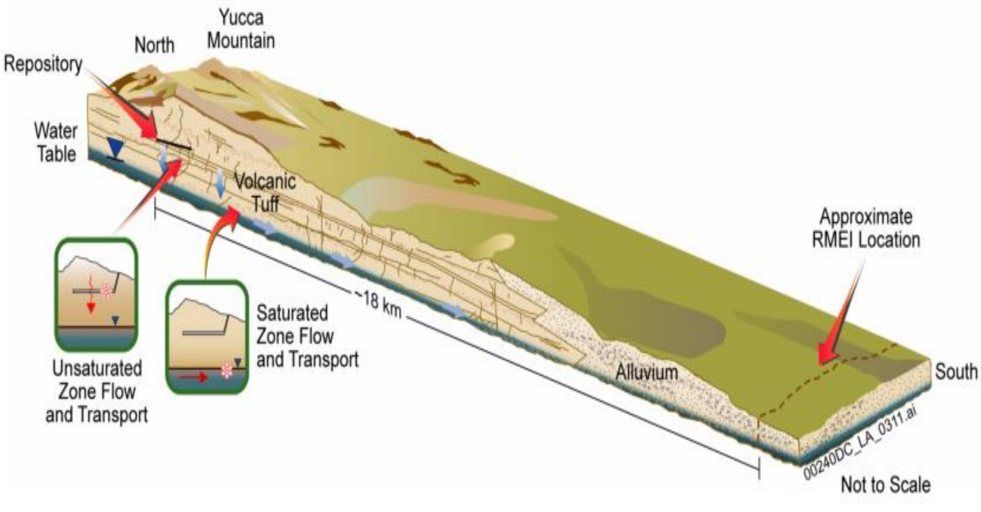

Figure 2-8. Illustration of the flow paths from the Yucca Mountain repository, through unsaturated and saturated zones and the location of RMEI.

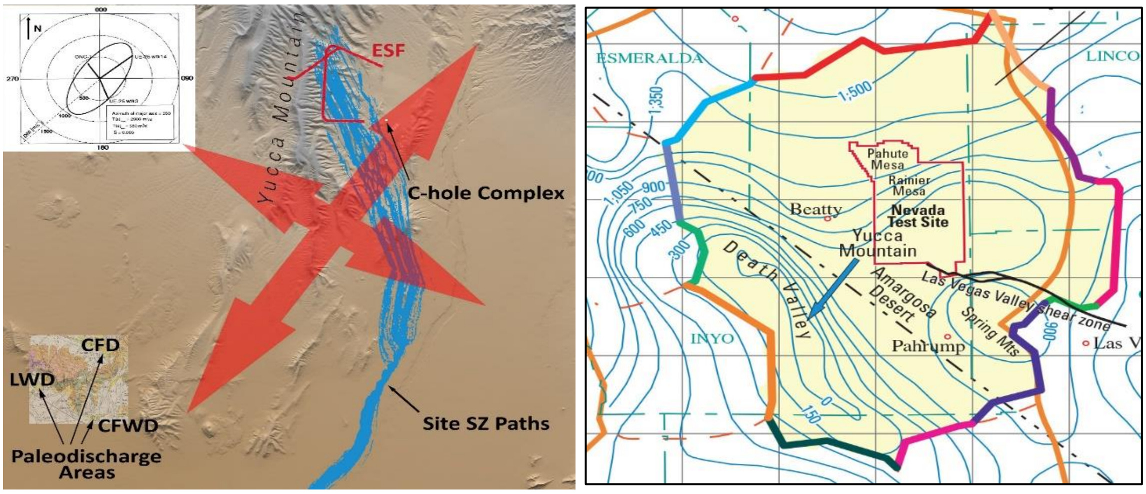

Figure 2-9. Site saturation zone paths at Yucca Mountain (left) and assumed perpendicular flow relative to contour lines (right).

It is difficult to know in detail where groundwater flows in this area, being a segmented, fault controlled system. There is a substantial gradient and it is a presumption that flow is perpendicular to the contour lines. There may not, however, be hydraulic coupling in the system – a hydraulic wall could be present, preventing groundwater flow. It is possible that, rather than a southward flow of all groundwater, there could be flow toward paleo-discharge areas during high flow conditions. As such, it is possible that the one story being told about discharge to a well may not be correct, as discharge could occur to another region. The assumptions around flow have been driven, in part, by the prescribed RMEI location with flow paths being back-estimated through the system.

Productivity in the region is driven by irrigation with circular agricultural areas being used for produce such as alfalfa. A volumetric extraction rate was prescribed in the regulations. The soils in the area are underlain by a caliche layer[h], and surface water percolating through the soil flows above this layer. This unusual occurrence highlights the need to consider the system before applying a general biosphere model and trying to force that model to address the system.

The assessment model applied is illustrated in Figure 2-10. Inhalation was found to be quite a significant exposure pathway due to groundwater being used to feed air conditioning systems in homes.

[h] A hardened natural cement of calcium carbonate that binds other materials—such as gravel, sand, clay, and silt.

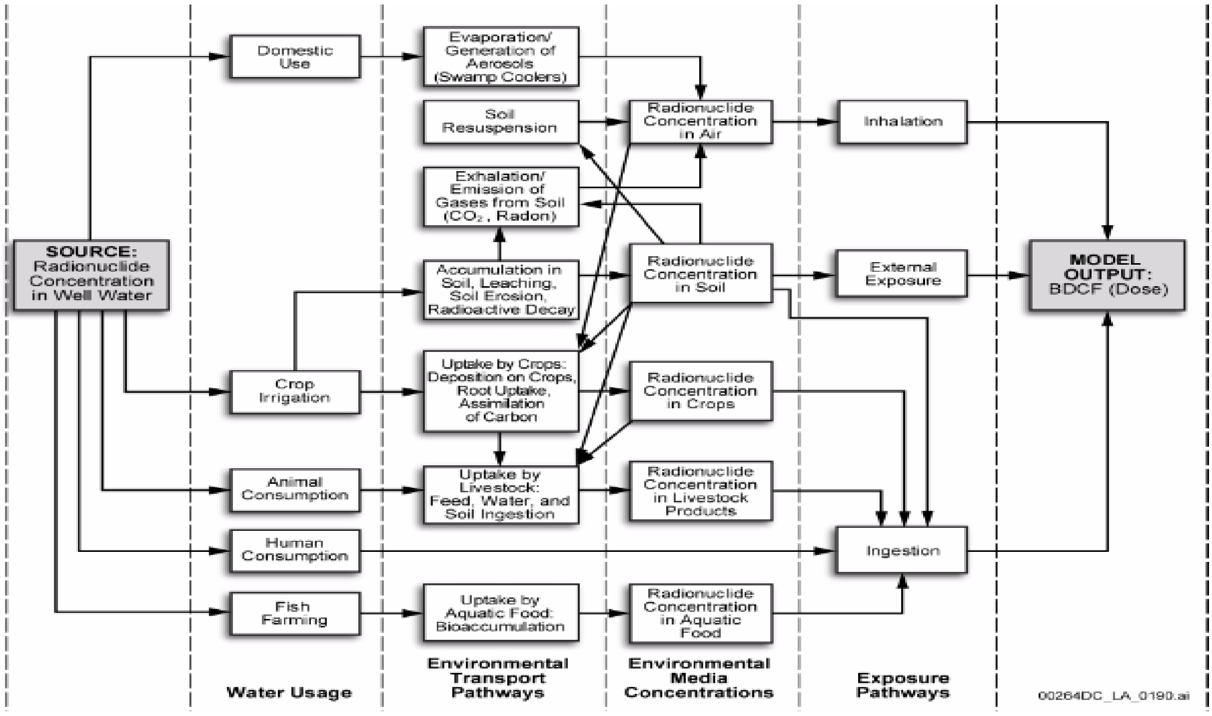

Figure 2-10. The Yucca Mountain biosphere assessment model, illustrating processes and pathways of exposure.

Whilst the BIOMASS methodology was not applied due to the prescriptive system, there was a comprehensive consideration of the system and pathways and an audit undertaken against a full survey of the habits and behaviour of people in the area and how they lived and a broadly fit-for-purpose model was developed. A FEP list was also applied, but rather than using a generic FEP list, a US DoE FEP report for Yucca Mountain was used that provided a comprehensive account of that repository system. The same systematic principles as those set out in BIOMASS were therefore applied and the assessment has many commonalities with the elements included in the reference biosphere 2A of the BIOMASS methodology.

Discussion

A prescriptive system applied to the exposed group forces prescription back through other parts of the system, which may not be appropriate. A key learning point from the assessment was that models must be built according to the system rather than taking readily available software / models and trying to force these to address the system.

It was required that a 10,000 year timescale be considered for Yucca Mountain and that events with a 1 in 10^6 risk of occurrence within that timescale be evaluated. This rule was however challenged, resulting in a 1 million year timescale being prescribed although only those FEPs of importance during the 10,000 year timeframe were required to be taken forward to the 1 million year timeframe. Paleoclimate data were used rather than a climate model to set the range on climate conditions for the first 10,000 years. For the post-10,000 year period, infiltration rates into the repository were stipulated by regulation.

2.7 STATUS OF POSIVA'S BIOSPHERE PROGRAMME

Lauri Parviainen presented.

A licence for the construction of a repository for spent nuclear fuel at Olkiluoto was granted in November 2015 and Posiva is now working toward an operational licence submission that is due at the end of 2020. The overall work flow is illustrated in Figure 2-11.

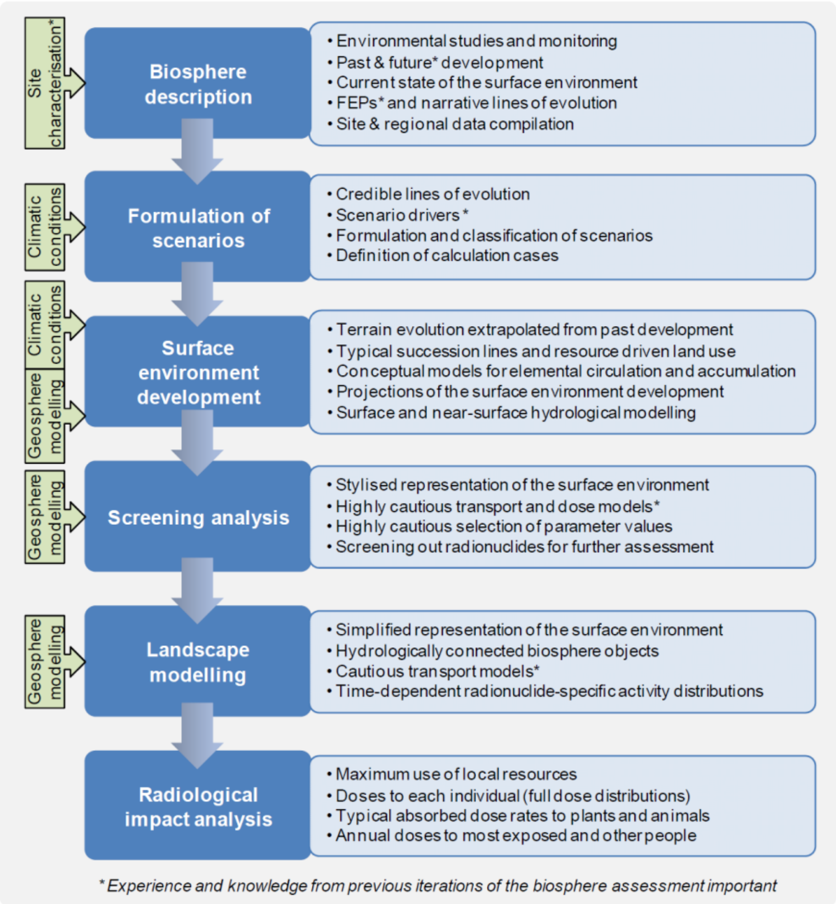

Figure 2-11. Outline of the programme of work for the biosphere assessment BSA-2020.

Since the BSA-2012 assessment, there have been many reports published and additional data have been generated from site characterisation programmes, including studies on aquatic environments and mires and on fauna. For the different biotopes studied (e.g. mires and lakes), biomass has been quantified and samples collected for elemental analysis to allow the calculation of concentration ratios. Dimensions of sampled fauna and flora have also been measured. For biota, the concentration ratios relative to stomach contents are being calculated for larger animals whereas for invertebrates the ratios are calculated relative to soil. Working reports on the field studies and associated data are all due to be completed by June 2017.

There are new elements to be considered in BSA-2020 with radionuclides identified as being of potential significance having varied over time. The elements that will be considered in BSA-2020 are those included in the construction license application (Ag, C, Cl, I, Mo, Nb, Se) plus several new elements (Cs, Ni, Pb, Pd, Sn and Sr).

A new screening of FEPs has also identified processes that are implicitly considered, such as soil splash leading to adhesion of radionuclides to the outer surfaces of plants. The processing and analysis of field samples is used wherever possible to address the processes. For example, plants harvested for elemental composition analysis are not washed prior to analysis so that results include any surface contamination. The calculated concentration ratios therefore account for any transfer of radionuclides to plants by soil splash.

The BSA-2020 biosphere programme is currently moving from a planning to an execution stage. Safety assessment modelling activities have already started and a safety case plan has been produced and is currently under review by STUK with comments being addressed as they arise. The plan is due to be published early 2017.

In terms of modelling activities, updates of the terrain and ecosystem model have been completed with a sedimentation model having been implemented based on reference lake data, the land uplift model has been revised and a new statistical approach taken to the overburden model that includes soil stratigraphy for the whole model area. Production modelling of the terrain and ecosystem model has begun, with output in terms of surface hydrology being required as input to the safety assessments of the engineered barriers. Input from the geosphere modelling team is required to identify discharge locations in the biosphere that will then allow for object delineation of the surface environment.

Climate has been modelled for the next 120,000 years with time steps of 1,000 years. Shorter time steps of 10 years have also been modelled for the first 10,000 years. Under a high sea level variant of a warmer climate case, sea level rises by 26 m and the island of Olkiluoto becomes very small. However, as post glacial land uplift continues the island increases in size again until the land form is similar to that in the last assessment. With a greater time scale being considered in BSA-2020, there is greater potential for mire formation and the mire model has therefore been updated. The frequency of mires formed is similar that of those that have formed in the region in the past.

Landscape modelling is being prepared to allow for a probabilistic approach to be taken. Learning from the BSA-2012 and from regulatory feedback, the number of landscape objects will be reduced to those that contribute to dose by modelling only those that could become contaminated. The probabilistic modelling with then focus on these fewer objects.

An update to the C-14 model is currently ongoing and it is planned that Hyytiälä forest station data will be used to validate the model. The model assumes a thick canopy and CO_2 profiles through the canopy will be needed. C-14 was the dominant radionuclide in BSA-2012 although doses were several orders of magnitude lower than the regulatory constraints. Nonetheless, the model is being updated to account for processes such as mixing with atmosphere and loss to atmosphere from lakes.

A data lock will occur at the end of 2016, after which time the radionuclide transport modelling activities will begin. A parallel, separate modelling tool 'SIPRO' will also be used for stylised radionuclide transport modelling of the disposal system, combining releases and doses from the spent nuclear fuel repository and the low and intermediate level waste repository that will be co-located. The model is being implemented in Ecolego and will allow sensitivity and uncertainty analyses to be undertaken. A report on this model should be available by the end of 2016.

Requirements from STUK have changed since the 2012 licence submission and have resulted in a need to consider a longer time scale for humans. A stylised approach to addressing lines of evolution of the surface environment over the longer timescales is however permitted, rather than undertaking detailed landscape terrain modelling. The SIPRO model may be used to evaluate doses for these longer timescales and different calculation cases.

Data management protocols have been updated to ensure that input data to the safety case are appropriately reviewed. All data must be accepted prior to use in the assessment and users are assigned different access levels to the database. The objective is to ensure traceability in data and maintain data quality.

The overall schedule for BSA-2020 is detailed in Figure 2-12. The main reports that will be produced include:

- Site description report (to include the old biosphere description) that is due to be published by the end of 2018.
- Models and data report (to include the old biosphere data basis) that is due to be published by the end of 2020.
- Analysis of releases report (to include aspects of the biosphere assessment), that is to be published by the end of 2020.
- Performance assessment and formulation of scenarios report, again to be published by the end of 2020.

All reports will be reviewed internally and externally prior to review by STUK. The operational license submission will be made in December 2020.

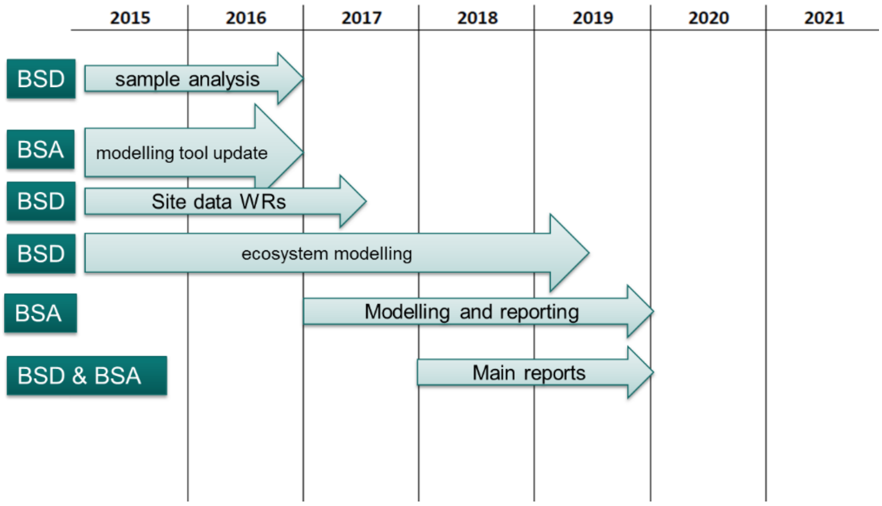

Figure 2-12. Schedule of BSA-2020.

Discussion.

STUK has set a requirement for the use of site-specific data and this has been interpreted as requiring the sampling and analysis of biota, which has been a driver for the faunal monitoring programme.

The assumption of 25 m sea level rise would equate to a high level of ice-sheet loss through global warming. A common strategy on assumptions concerning the behaviour of the continental ice sheets under different global warming scenarios is needed to avoid unwarranted different assumptions in assessments.

Within the BIOMASS methodology, landscape modelling is not included as a specific task. This can however be an important tool for defining input data for the assessment. It also identifies the location of discharge points and, hence, identifies the geosphere-biosphere interface. The use of simple parallel model assessments could also be added to the enhanced methodology. BIOMASS focusses on the development of an assessment model and does not address how supporting models should be developed, such as landscape models. It is not therefore as explicit as it could be and there could be merit in providing examples as to how such models can be deployed in assessments.

2.8 REMOTE SENSING AND TERRAIN MODELLING

Tarmo Lipping and Jari Turunen presented.

A probabilistic terrain model has been developed for Olkiluoto to evaluate post-glacial land uplift, taking into account uncertainties. The BIOMASS methodology has recently been retrospectively applied.

The current rate of land uplift at Olkiluoto is around 6 mm/year. To investigate the potential future land evolution, a digital terrain model that includes sea bottom elevation was required. Terrestrial terrain is quite easy to evaluate, but for the seabed, data from various sources were required. The data sources, illustrated in Figure 2-13, included:

- Finnish Maritime Administration data;
- Sonar measurements;
- Acoustic-seismic measurements;
- Precision levelling; and
- Seismic measurements.

The use of a variety of sources introduced errors and uncertainties, some of which were substantial (e.g. ± 5m in some areas). For each area of the model, an error distribution was produced to allow a probabilistic analysis of the terrain with 95% confidence limits for each point. The greatest errors were associated with the open sea areas where data were less comprehensive. An illustration of the results is provided in Figure 2-14.

For land uplift, two alternative approaches can be employed. A semi-empirical approach draws upon past land uplift data. Alternatively, geophysical models can be used. For this project, the semi-empirical approach was employed with data on previous land uplift being used to derive the distribution of model parameters. Archaeological data points above sea level were used to evaluate error along with radiocarbon data to define their ages.

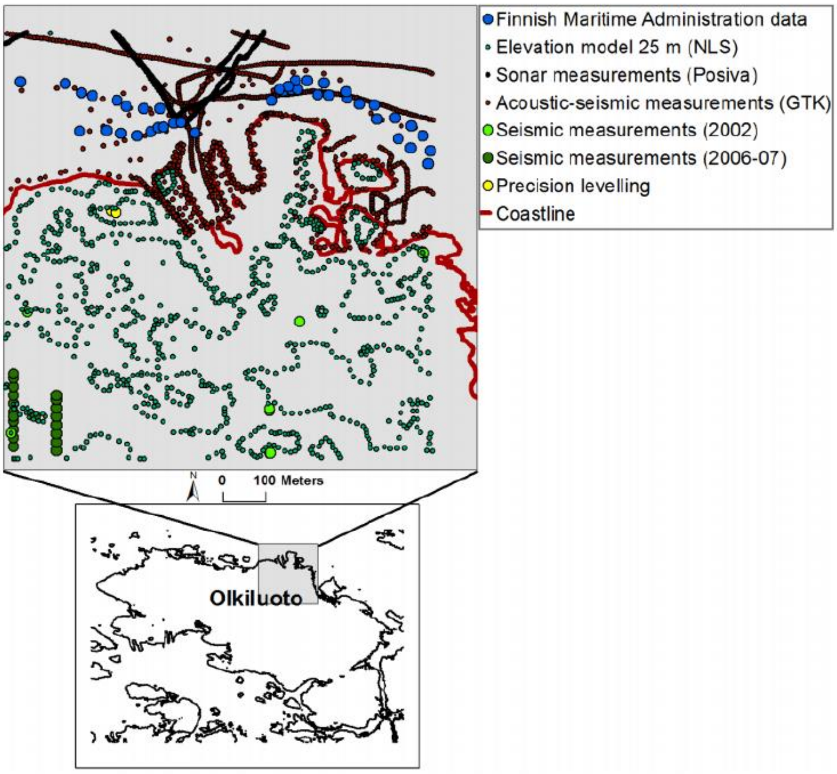

Figure 2-13. Topography source data for the creation of a digital terrain model for Olkiluoto.

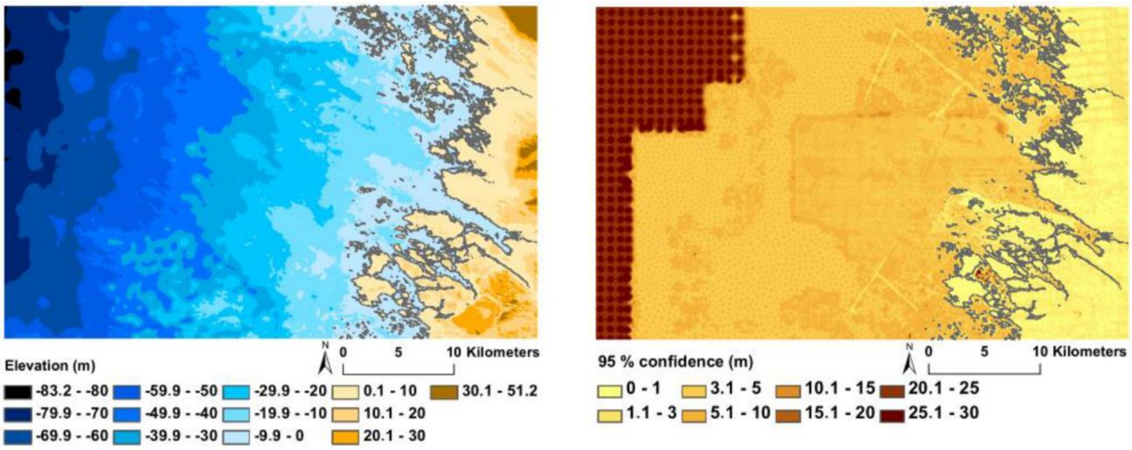

Figure 2-14. Digital terrain model (left) with 95% confidence limits (right) of the Olkiluoto coastal area.

To project terrain development over the next 10,000 years, 1,000 year time steps were used and both slow and fast uplift components considered along with isostatic sea level changes. Different versions of the terrain development reflect the different data. Four lakes are observed to form as more land areas are formed and the probability of the lake area and depth were assessed (Figure 2-15). When combined, it was possible to develop 3D lake models (see Figure 2-15).

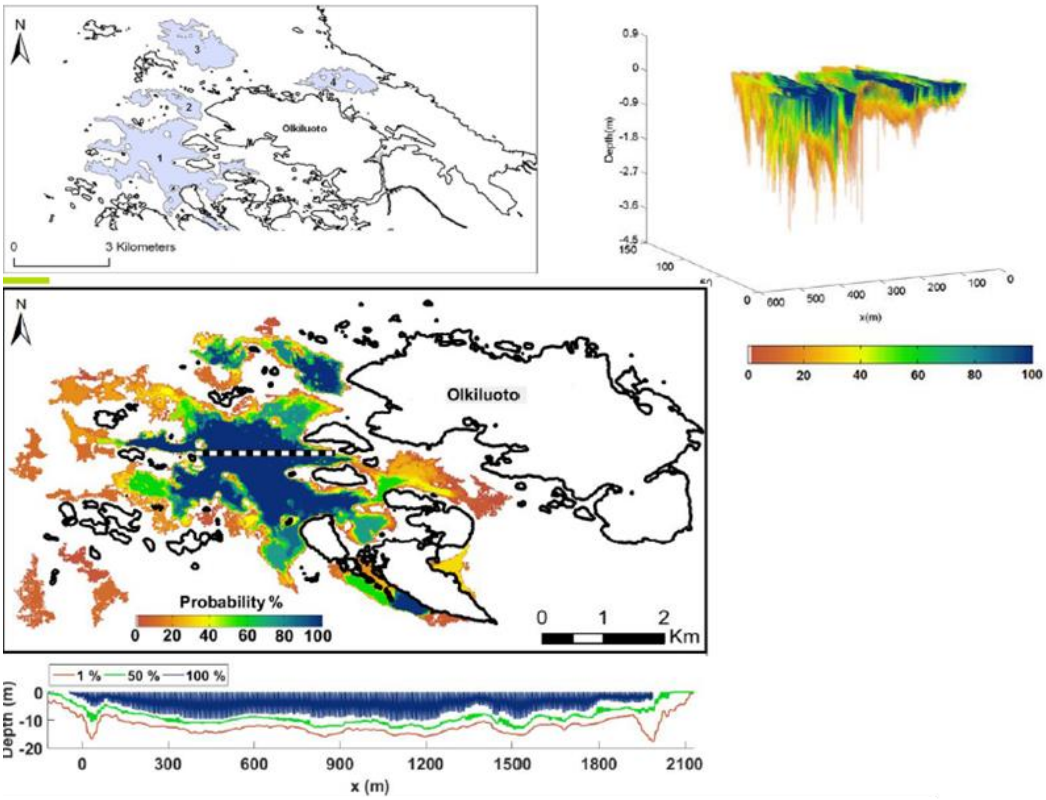

Figure 2-15. Location of lakes (upper left) as new land areas develop around Olkiluoto and lake area (middle left) and depth (lower left) and the resultant 3D lake model output.

The terrain model has also been used to model the catchment areas of rivers, the location of river beds and how river beds change as land uplift continues in a probabilistic manner (Figure 2-16).

The lake model has been incorporated within an Ecolego dose model with the lake replacing a well such that drinking and irrigation water are sourced from the lake. Currently the discharge of radionuclides to the lake from a repository is to the lake water, but consideration is being given to the sediments of the lake being the point of input. Work is therefore progressing to look at the accumulation of radionuclides in sediment layers and how this decreases dose.

Diet assumptions were derived from statistics on the average diets of Finnish people with both mean and standard deviations being used as input to Monte Carlo simulations of different scenarios to derive dose conversion ratios relative to different foods. This analysis provided information on what were, for different radionuclides, the dominant features affecting the dose conversion ratios. The dominant features varied with radionuclide. For example, the Kd for soil was important for chlorine whereas for strontium the soil-to-plant concentration ratio was dominant. The dose conversion ratio was also calculated for different foods to identify the dominant pathways leading to dose from a unit release.

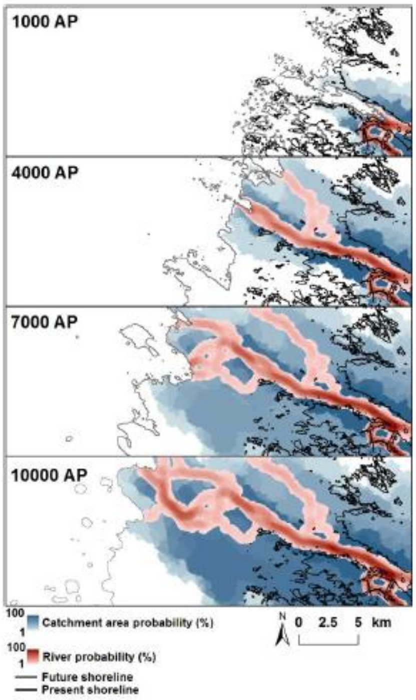

Figure 2-16. Probabilistic evolution of river and catchment areas [Pohjola et al, 2016[i]].

Results of the 3D probabilistic lake model have been compared with data from an existing lake in Finland. Results were found to be similar in terms of mean inflow and outflow rates etc.

The BIOMASS framework was not used in the initial development of the models, but in later work the methodology was considered in a back-fitting approach whereby FEP lists were used to identify those features that were important and to justify those that were not. The different parameters etc. were also all described. The use of the methodology in a back-fit approach was however laborious.

Future work will involve undertaking sensitivity analyses for different biosphere cases where the base scenario is the release of radionuclides to a lake, but where discharge also occurs to forests or mires, either through direct discharge or as a result of lake flooding, to consider the circulation of radionuclides in those systems.

The work presented is discussed in a number of publications:

- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2016. Probabilistic assessment of the influence of lake properties in long-term radiation doses to humans. *Journal of Environmental Radioactivity*, 164, pp. 258-267.

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[i] Pohjola et al (2016). Probabilistic framework for modelling the evolution of geomorphic features in 10,000 year time scale: The Eurajoki River Case. Lecture Notes in Geoinformation and Cartography. Sarjakoski, T, Santos MY and Sarjakoski T (eds), Geospatial data in a changing world – selected papers of the 19th AGILE Conference on Geographic Information Science. Springer, p. 367-380.

- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2014. Biosphere development modeling based on statistical framework. *Computers & Geosciences*, 62, pp. 43-52.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2013. Evaluation and Assessment of Arctangent based Post-glacial Land Uplift Model. *EARSel eProceedings*, 12: 2, pp. 82-93.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2016. Probabilistic framework for modelling the evolution of geomorphic features in 10,000-year timescale: The Eurajoki River case. *Lecture Notes in Geoinformation and Cartography.* Sarjakoski, T., Santos, M.Y. and Sarjakoski, L.T. (eds)., Geospatial Data in a Changing World -Selected papers of the 19th AGILE Conference on Geographic Information Science. Springer, pp. 369-382.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K.,, 2010. Statistical estimation of land uplift model parameters for landscape development modeling in ArcGIS environment. *Advances in Geoinformation Technologies 2010*. Jiri Horak, Lena Halounova, Tomas Hlasny, Dagmar Kusendova and VitVozenilek (Eds.), VSB-Technical University of Ostrava, Czech Republic, pp. 121-134.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2009. Creation and Error Analysis of High Resolution DEM Based on Source Data Sets of Various Accuracy. *3D Geoinformation Sciences: Lecture Notes in Geoinformation and Cartography,* Jiyeong Lee, Sisi Zlatanova(Eds.), Springer-Verlag, Berlin, Germany, pp. 341-353.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2016. The influence of food stuff grouping on doses in safety assessments. Ninth International Conference on Nuclear and Radiochemistry-NRC9, P2-118.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2012. Evaluation and assessment of Arctan-based Post-glacial land uplift model. *4th international workshop of the EARSeL Special Interest Group "Geological Applications" - Workshop Proceedings, 24-25 May 2012, Mykonos, Greece,* Konstantinos Nikolakopoulos, (ed.). pp. 52-60.
- Pohjola, J., Turunen, J., Lipping, T., 2011. Påsse's Semi-Empirical Model Re-Implemented. Proc. of Seminar on Sea Level Displacement and Bedrock Uplift, 10-11.6.2010, Pori, Finland, Ari Ikonen and Tarmo Lipping (Eds.), Posiva Working Report 2011-07, Posiva Oy, Eurajoki, Finland, pp. 37-46.
- Turunen, J., Pohjola, J., Lipping, T., 2011. Dating of Past Coastline Positions -Challenges of Using the Various Types of data as Input to Modelling. Proc. of Seminar on Sea Level Displacement and Bedrock Uplift, 10-11.6.2010, Pori, Finland, Ari Ikonen and Tarmo Lipping (Eds.), Posiva Working Report 2011-07, Posiva Oy, Eurajoki, Finland, pp. 17 -24.
- Pohjola, J., Turunen, J., Lipping, T., Ikonen, A.T.K., 2014. The Estimation of Future Surface Water Bodies at Olkiluoto Area Based on Statistical Terrain and Land Uplift Models. Posiva Working Report, 2014-11. Posiva Oy, Eurajoki, Finland.
- Pohjola, J., Turunen, J., Lipping, T., 2012. Statistical estimation of land uplift model parameters based on archaeological and geological shore level displacement data. Posiva Working Report, 2012-86. Posiva Oy, Eurajoki, Finland.

- Pohjola, J., Turunen, J., Lipping, T., 2009. Creating high-resolution digital elevation model using thin plate spline interpolation and Monte Carlo simulation. Posiva Working Report, 2009-56. Posiva Oy, Eurajoki, Finland.

Discussion

In considering uncertainty, it is important to understand correlations to ensure that realistic combinations of parameters are included in an assessment model. It is however difficult to consider correlations when doing probabilistic assessments. The need to consider correlations in parameters was not explicit within the BIOMASS methodology.

2.9 THE INFLUENCE OF CLIMATE AND PERMAFROST ON CATCHMENT HYDROLOGY

Emma Johansson presented.

In order to understand and assess the impact of a repository on the system in which it is located, interactions between groundwater and surface water must be known. A good understanding of hydrological systems has been developed over the years for temperate systems. However, hydrology under periglacial climate conditions is relatively poorly understood, but could be of importance in assessing the safety of radioactive waste repositories. As such, a project has been undertaken by SKB to gain a better conceptual understanding of hydrology under periglacial conditions. Of particular interest was the interaction between the permafrost active layer[j] and taliks[k] and in the transitional period from temperate to periglacial conditions (Figure 2-17). Under temperate conditions, radionuclides released from a repository might be transported with both deep and shallow groundwaters. However, under periglacial conditions, flow paths may be cut off, forcing radionuclides transported in groundwater to be redirected to taliks. Climate can therefore affect discharge areas in the biosphere. The aim of the project was therefore to increase the understanding of catchment hydrology in periglacial landscapes with permafrost. The project had the following three key objectives:

- Quantify the hydrological effects of landscape, climate and permafrost changes;
- Investigate the role of taliks on the exchange of deep and shallow groundwater; and
- Develop an understanding of the spatial and temporal variability of water flows in a periglacial catchment.

Modelling studies have been undertaken for two sites – Forsmark in Sweden and Two Boat Lake in Greenland. Existing site data from Forsmark were applied whereas for the Greenland site, which is close to the Greenland Ice Sheet, data were collected and analysed as input to the study. The range of field investigations undertaken to derive data collected is illustrated in Figure 2-18.

[j] The uppermost layer that thaws and freezes seasonally, depending on weather conditions.

[k] Unfrozen areas in the permafrost often found under larger water bodies.

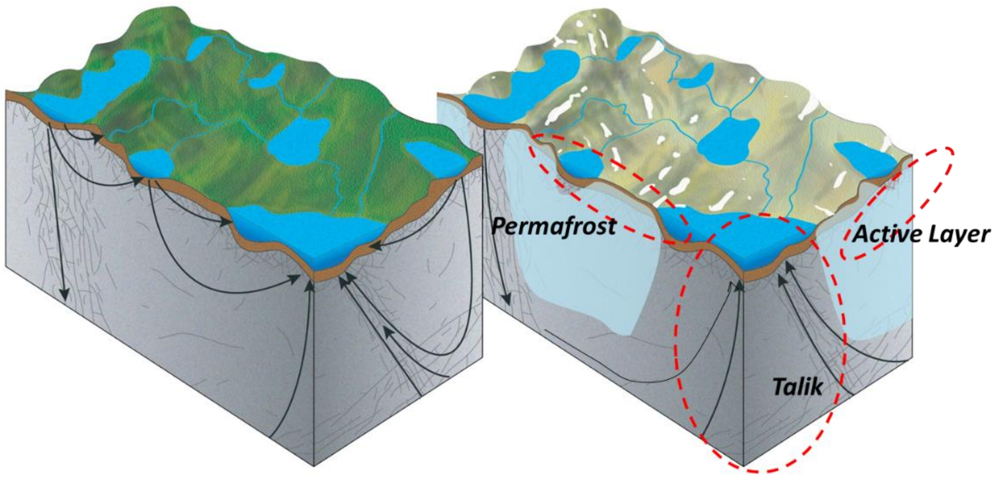

Figure 2-17. Illustration of the interactions between surface water and groundwater under temperate (left) and periglacial (right) climatic conditions.

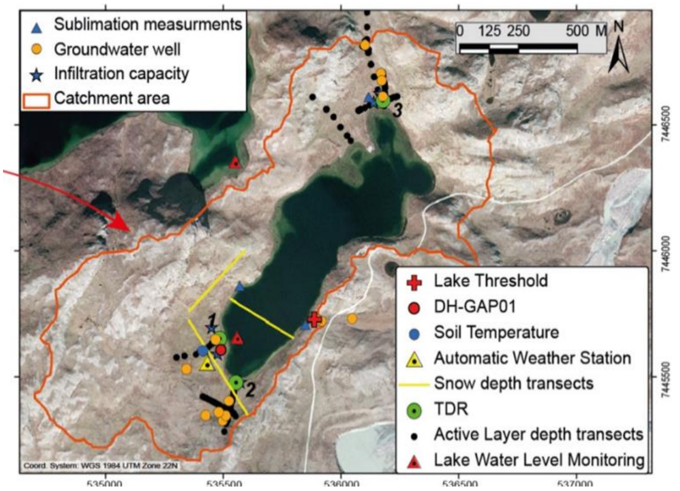

Figure 2-18. Field investigations at Two Boat Lake in Greenland to derive data in support of the development of hydrological models under periglacial conditions.

Numerical modelling was undertaken using MIKE SHE. The model for Forsmark was calibrated and validated against present day data. There are no thermal components in MIKE SHE and hydraulic properties were therefore controlled by soil temperature when permafrost was simulated. Low hydraulic conductivity was assigned to frozen areas, since water would not flow, whereas for the active layer, which freezes and thaws on a seasonal basis, time varying hydraulic properties were assigned, based on site soil data for summer and winter conditions. Taliks remain unfrozen at all times and water was therefore allowed to flow in these areas all year round.

Two papers have been produced for the Forsmark site. The first paper was focussed on quantifying the hydrological response of the catchment to climate and landscape changes. The second paper focussed on the exchange of deep and shallow groundwater and the role of taliks.

Shoreline displacement will lead to new land and lake areas forming over the next 10,000 years, which will affect the hydrological system. This in turn will be affected by changes in climate. To investigate the influence of climate and landscape changes, a stepwise approach was taken whereby an existing site-specific hydrological model of Forsmark was calibrated for landscape changes resulting from shoreline displacement over a 10,000 year period (consistent with when the next glaciation event could occur). Surface climate changes were then considered and finally, permafrost formation was included. Climate and the formation of permafrost were found to have at least as much influence on the hydrology of the area as landscape change. The temporal variation in hydrological conditions under different climate conditions is illustrated in Figure 2-19. Under a temperate climate there is considerable variation in run-off across the year. However, under a periglacial climate, there is no run-off throughout the entire frozen period of the year, but at the beginning of the active period there is a rapid change in run-off observed. A similar pattern is observed for infiltration and groundwater recharge. Spatial variation in groundwater recharge and discharge is also observed. During temperate climate conditions, a scattered pattern of recharge and discharge occurs whereas during periglacial conditions when permafrost occurs, discharge areas may be closed and recharge to groundwater reduced, both as a result of a shorter hydrologically active period and also because recharge is only possible in talik areas when permafrost is present. Permafrost influences both the magnitude and the direction of groundwater flow with some recharge areas changing to discharge areas and vice versa when permafrost was included in the model.

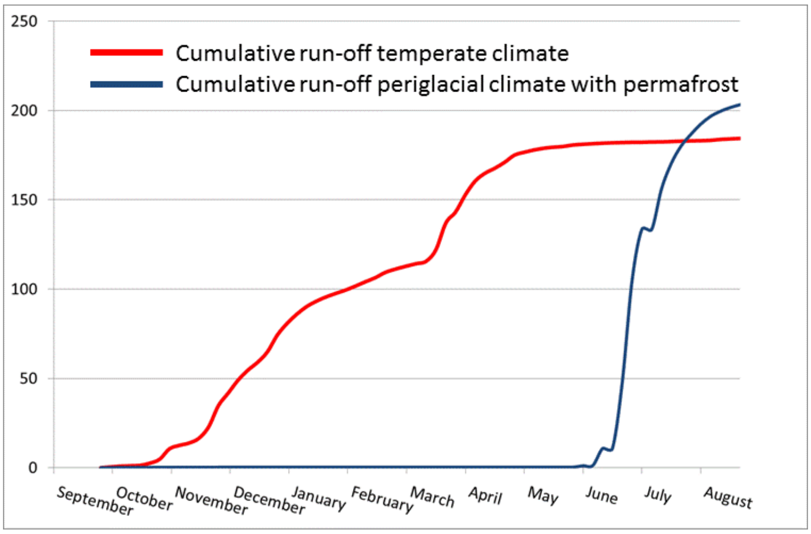

Figure 2-19. Temporal variation of storage and water flow components under temperate and periglacial climate conditions.

Following the completion of modelling studies for Forsmark, work was undertaken for the study site in Greenland and a further two papers have been published. The studied catchment is located close to the Greenland ice sheet and has deep permafrost throughout. A talik is present below the lake, as confirmed by borehole drilling. The whole system was conceptualised and models developed. Site investigations allowed the water balance of the catchment to be quantified with a range of measurements taken, including snow depth, rainfall, evapotranspiration, soil temperature, moisture and hydraulic properties and lake water level and inflow. The lake is precipitation driven, with no surface water or glacial melt water inflow. The catchment is situated in a very dry area and conventional measurement techniques such as surface water discharge measurements were not therefore appropriate. Time-lapse cameras were therefore used to record pictures of the catchment. These were used to help understand outliers in monitoring data and to increase the conceptual understanding of the site through the coupling of meteorological and hydrological data to photos from around the site throughout the year.

Conceptual models for both active and frozen periods have been developed (Figure 2-20) on the basis of the understanding gained. During the active period, groundwater can flow in the active layer and surface water can flow both in and out of the lake. There is also groundwater exchange between the lake and the talik. During the winter, all surface hydrological components become inactive and the only active components are the exchange of water between the lake and talik and a very low exchange between the talik and deep groundwater.

The conceptual models have been used as the basis for numerical model development, driven by local data. The model has been used to quantify the water balance of the catchment and to study the temporal and spatial variability of water flows and exchanges between the lake and talik. The water balance under normal weather conditions is illustrated in Figure 2-21. The temporal variation of the lake level is governed by evaporation and evapotranspiration in the summer leading to a reduction in water level and by rapid thawing of the active layer in the spring resulting in an increased water level. The lake water and catchment hydrology are independent of what is happening in the bedrock. Talik recharge is only a small component of the overall water balance and is not sensitive to temporal changes in bedrock groundwater pressure.

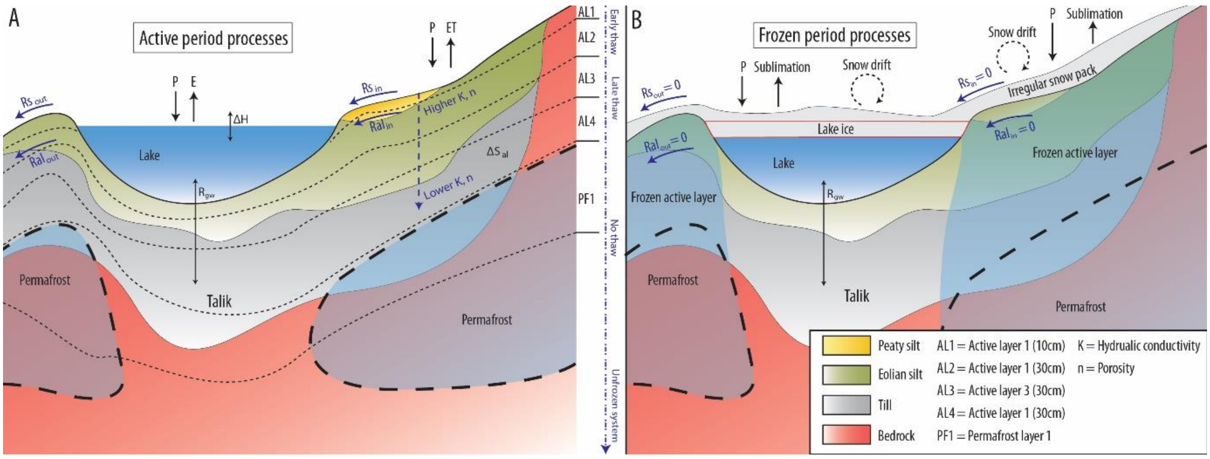

Figure 2-20. Conceptual model of the Two Boat Lake catchment in Greenland under both active (left)) and frozen (right) phases.

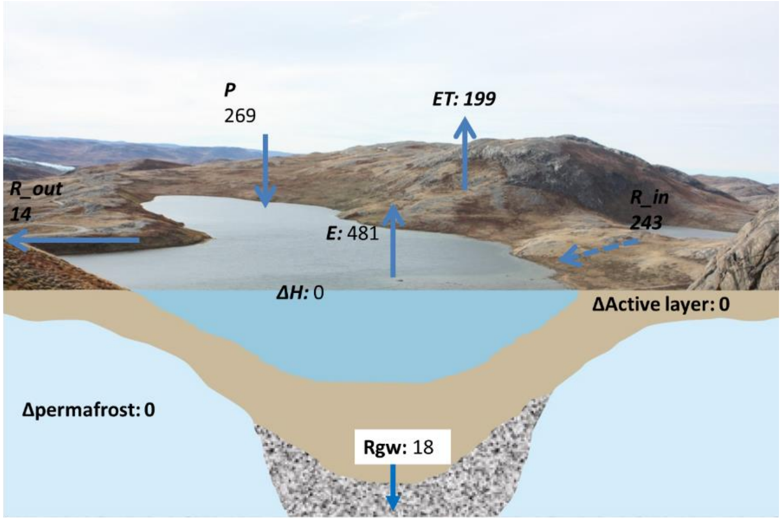

Figure 2-21. Water balance of the Two Boat Lake catchment under normal weather conditions, illustrating precipitation (P), evaporation (E), evapotranspiration (ET), inflow (R in), outflow (R out) and lake recharge to the talik (Rgw).

All data generated from the site studies have been published and are freely available in a PANGAEA database[l]. Bio-geological data and data on the geometries of the catchment are also available as PANGAEA databases to allow conceptual and numerical models of the system to be set up[m].

From the work undertaken, conclusions relevant for the BIOMASS update were drawn:

- To understand the partitioning of water in the landscape both subsurface and surface hydrology should be considered together as interactions are important and cannot be separated.
- Model results suggest that permafrost has larger influence on the catchment hydrology than landscape succession during temperate conditions.
- Groundwater flow in taliks is small compared to other water balance components. However, although the flow may be low, taliks may be "hotspots" in a periglacial landscape with groundwater carrying radionuclides up to the biosphere over long time frames.
- Permafrost may change the general flow direction of groundwater. The spatial distribution of recharge/discharge areas is not, therefore, constant in time.

Discussion

To impose permafrost on the Forsmark system, a possible climate evolution was considered and a climate time series of permafrost was simulated to describe the hydrological dynamics in the active layer. Permafrost modelling used a number of conditions on the depth and radius of lakes and their

[l] https://doi.pangaea.de/10.1594/PANGAEA.836178.

[m] Available from PAGAEA/de, using Emma Johansson as a search input.

bottom temperatures to determine the number and location of taliks with a number of future lakes being of a size sufficient to maintain taliks. The taliks were represented as unfrozen columns within the MIKE SHE model. The location of the taliks governed groundwater fluxes.

The number of potential areas exposed to radionuclides are fewer under periglacial conditions than temperate conditions as radionuclides are concentrated to talik areas. Transport in periglacial conditions is slower, but over long timeframes radionuclides can concentrate in taliks and exchange with their supporting lakes. These lakes may be the only potential food sources for people under periglacial conditions. Data collated from studies in Greenland on the biology of the system and biogeochemistry may be useful in understanding the sustainability of populations inhabiting periglacial systems.

2.10 THE ROLE OF INDEPENDENT MODELLING FOR SUPPORTING REGULATORY REVIEW OF DOSE ASSESSMENTS

Shulan Xu presented.

SSM has undertaken several decades of model development work, both in house and through the use of external expertise. The overall objective has been to develop an independent modelling capacity to allow regulatory review of SKB's post-closure safety assessment for a spent nuclear fuel repository (SR-Site). This has involved the use of SKB's own models, use of alternative conceptual models and the use of bounding calculations. The overall review strategy is illustrated in Figure 2-22, with decision points being used to guide activities.

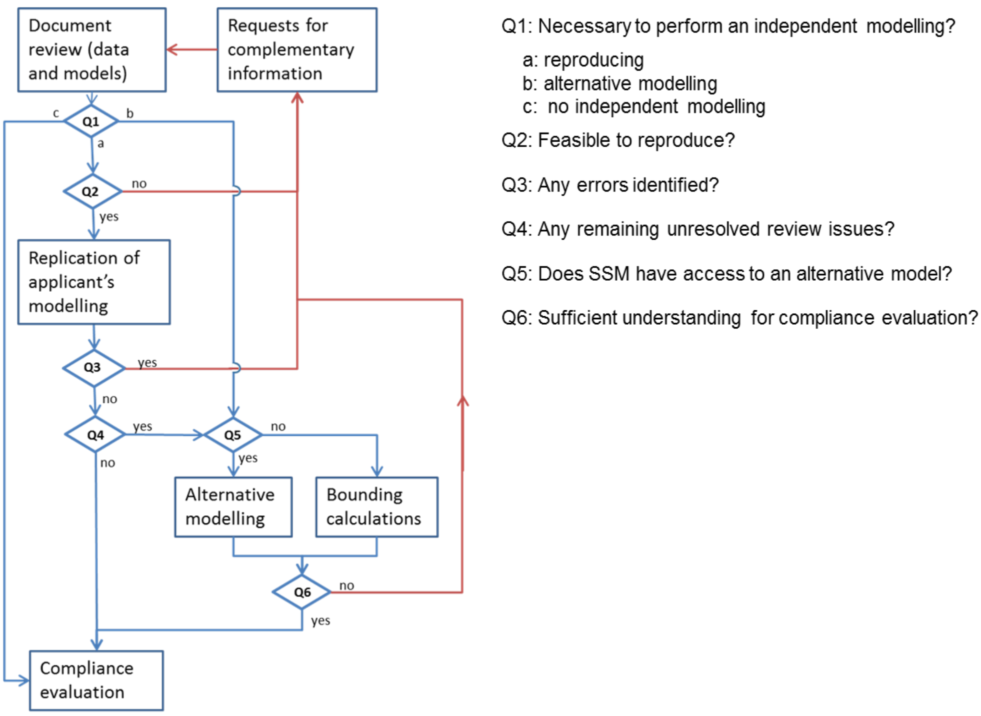

Figure 2-22. Strategy for the regulatory review of SR-Site.

A license submission was made by SKB in 2011 for a KBS-3 type repository for 12,000 tonnes of spent fuel, supported by the SR-Site post-closure safety assessment. The review of this application is nearing the final stages and has involved 50 SSM staff, supported by over 40 international experts. The review, which involved both document review and independent modelling, has resulted in more than 90 external expert technical notes and over 80 requests for complimentary information. A final review statement is expected in 2017.

The modelling chain used by SKB in the SR-Site assessment is illustrated in Figure 2-23. Biosphere modelling was decoupled from the geosphere. The biosphere model was used to derive landscape dose factors (LDF), defined as the annual effective dose to a representative individual resulting from a constant unit release rate (Sv/y per Bq/y). These were then used in conjunction with releases from the geosphere to calculate doses to potential exposure groups under different release scenarios.

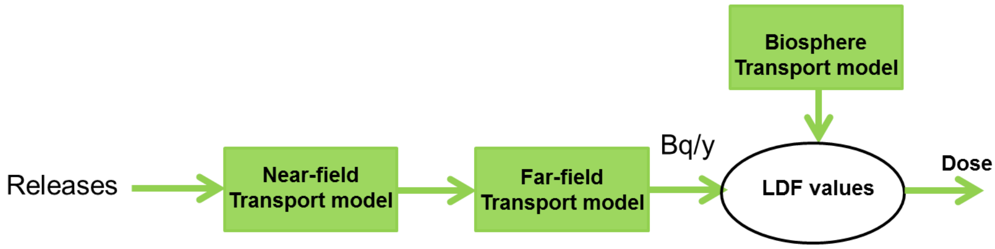

Figure 2-23. SKB's models for consequence analyses in SR-Site.

The Forsmark region is subject to post-glacial land uplift that is projected to continue over the next 10,000 years or more. As the land rises there are transitions from marine to lake, mire and forest areas and the potential for agricultural exploitation of these new terrestrial areas. To estimate the radiological risk to people and the environment, the approach of SKB in SR-Site was to be as realistic as possible and to use measured data from the site. The evolution of the system was modelled using a series of models and steps with more than 10 reports providing the basis to the LDF values. For example, hydrological flow models were used to identify release areas to the biosphere with these areas being represented as biosphere objects. Radionuclide transport models were used to evaluate transport through and between these objects, with the change in the biosphere being assessed using time varying data from a landscape model as input to the LDF model which was run for each biosphere object assuming a constant unit release rate. The maximum LDF for all objects, irrespective of time was then selected for the assessment of dose. The approach therefore was very complex and the documentation was not always clear and transparent. Ensuring that the biosphere assessment is transparent is very important however for building public confidence in the safety assessment.

The modelling undertaken by SSM aimed to reproduce the LDF values through review of the models used, discussions held with SKB and requests for complementary information. This process helped identify issues that required further in-depth review. Alternative biosphere models were also used to explore model uncertainties. For example, a simple reference biosphere model was developed, based on the BIOMASS methodology. GEMA-Site models that included biosphere evolution were also employed.

The simple reference biosphere model was developed using a BIOMASS type of approach. Biosphere objects were identified, such as lakes, mires and agricultural land using a general structure to describe the different objects, as illustrated in Figure 2-24. The resultant models allowed a deterministic approach to be taken to deriving LDFs for the landscape objects, without landscape evolution in the biosphere objects. SR-Site data were used as much as possible in the models to ensure a meaningful comparison.

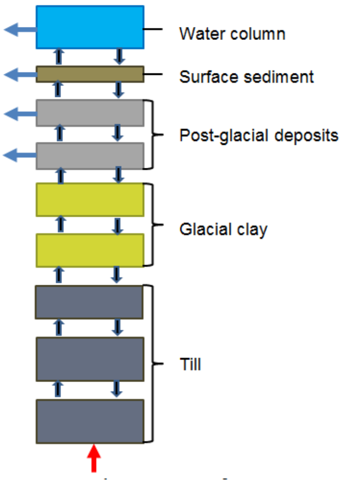

Figure 2-24. Illustration of the representation of biosphere objects in a simple reference biosphere model.

The highest LDF was associated with agricultural land and use of a deep groundwater well. Drinking water contributed over half of the derived dose from this scenario for 32 of the 39 radionuclides studied. A comparison of the LDFs calculated with the simple model against those calculated by SKB was made (Figure 2-25). The LDFs were found to be broadly within a factor of 10 of each other for the majority of radionuclides.

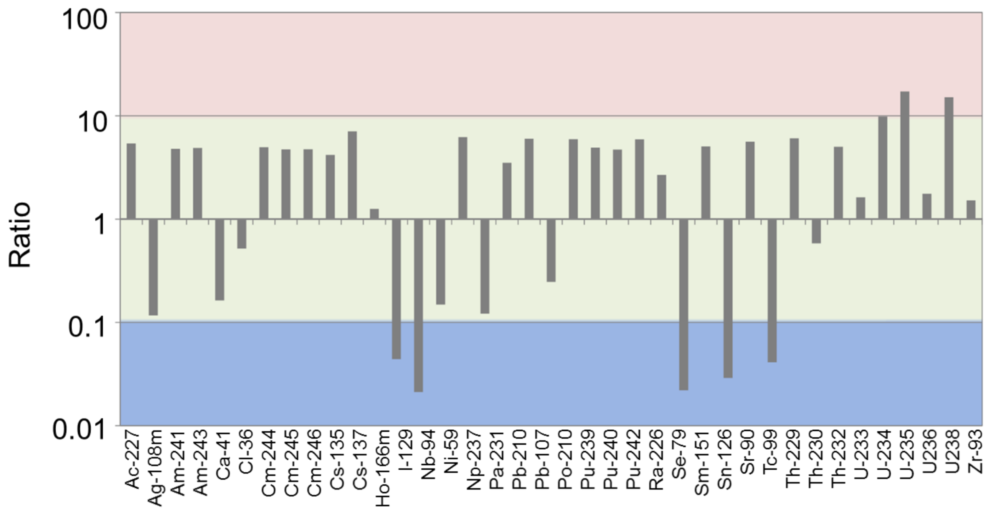

Figure 2-25. Ratio of the maximum biosphere dose factor with the reference biosphere modelling approach compared to the SR-Site LDFs.

The GEMA-Site model again represented single biosphere objects, but used a probabilistic approach to investigate the uncertainties around object and catchment size and of time to transition to agriculture on the LDFs. Results indicated that an increased accumulation time of 5,000 years prior to transition to agriculture affected the LDFs by less than a factor of five. Time to agricultural transition did not therefore have a significant effect on the calculation of LDFs. The effect of object size relative to catchment area again indicated that the LDFs were not significantly affected – decreasing the land area of an object relative to the catchment area by a factor of ten resulted in a less than factor of five difference in the LDFs, with the degree of effect varying according to whether the radionuclides were sorbing or not.

The overall findings of the review were that SKB's description of the methodology for the biosphere assessment was comprehensive and scientifically interesting and that LDF values were generally not underestimated for important radionuclides for releases to surface soils/sediments via groundwater. The preliminary review conclusion is therefore that SKB has the potential to comply with SSM's post-closure radiation safety regulations. The review was supported by independent modelling, which helped to identify issues requiring more detailed consideration, supported requests for further information and was important in building confidence in the assessment.

Discussion

The dominance of the drinking water pathway in governing dose masked the effects of changes in the biosphere from, for example, a reduction in the size of biosphere objects relative to the catchment area and may help explain the observed non-linear response. Non-linear responses are still observed however when wells are excluded, due to decay chains complicating radionuclide behaviour in the system.

The objective of the use of independent modelling was to explore differences arising from the use of different approaches rather than investigating the effect of variations in habit assumptions. As such, the review drew as much as possible on SKB data to avoid arbitrary assumption differences. If habit surveys are used in an assessment and it is assumed that the foods eaten are all obtained locally then this can lead to a very conservative assessment, since it may not be feasible for the local area to sustain the levels of productivity required. If, however, foods are assumed to be obtained from outwith the assessment area then doses will be diluted. There is therefore a need to consider how uncertainties around group habits, based on local surveys, should be taken into account in assessments. Including aspects around consumption habit assumptions may therefore merit consideration in the enhanced methodology, including alternative ways of deriving habit data, such as looking at the physical constraints of the system and the selection of appropriately cautious parameters.

The results of local habit surveys can change over time, leading to potential exposure groups being updated through different stages of repository assessment programmes. Habit surveys from further afield may also be required as input to addressing exposure under different climate assumptions. There is a need to ensure continuity in assessments and issues can arise if there are sudden changes. Care should therefore be taken in explaining any lack of continuity in assumptions through different stages of the assessment process. It should also be recognised that habit surveys will not necessarily address all habits. For example, illegal fishing and hunting will not be reported, but those undertaking such habits could be the most exposed due to gathering foods from the local area. Care should also be taken in using national habit data. Such data can be useful in defining some consumption rates, but communities will differ in their habits. For example, coastal communities will have very different habits from inland communities. Surveys should therefore be focussed on the communities of interest to ensure that habits such as higher than national average fish consumption etc. are captured.

3. DISCUSSION ON THE METHODOLOGICAL ENHANCEMENT REQUIREMENTS

The discussion session was structured around the original BIOMASS methodology and was aimed at identifying and discussing areas of enhancement that should be taken forward. The different aspects discussed are summarised below

3.1 ASSESSMENT CONTEXT

The assessment context is the first step in the BIOMASS methodology and it is intended that the underlying premises of the calculations (what is being calculated and why) be stated explicitly. It can however be difficult to determine exactly where the methodology starts within that context. For example, climate and landscape studies set a context for which biosphere models then need to be developed. It is clear from experience that the biosphere is sometimes treated separately from other parts of the system, whereas in others it is integrated with the geosphere. Irrespective of the approach, consideration has to be given to the system as a whole – the biosphere should not be considered in total isolation. Preferably, an assessment context should be developed for the entire assessment, and the biosphere be included within that.

The assessment context may change through different stages of a repository programme, from site-generic through to site-specific assessments, and should detail those aspects that can reasonably be known prior to the overall methodology being applied, such as overall climate and landscape concepts and regulatory expectations. The objective is not just to set out the why behind the assessment, but also to set out the expectations and level of ambition. There have been several assessments undertaken and the contexts of those can be reviewed to identify those aspects that could be considered reasonable and appropriate for inclusion in the enhanced methodology.

3.1.1 Repository system

BIOMASS was focussed on high level waste and associated long-term assessments. Consideration needs to be given as to whether the revision should encompass near-surface facilities etc. There was consideration of different repository types within MODARIA I and this information could be linked in to the revised methodology.

3.1.2 Timeframe

The time frame of the assessment should be clearly set out in the assessment context.

The time frame is not just about the end of the assessment; there may be a need to focus on the different times within the overall assessment time frame. For example, there could be greater interest in what happens at early times after closure. There may be times at which particular events could occur, for example being linked to landscape change or to changes in climate or to engineering degradation. The threats to the safety of the repository should be stated to allow understanding to be developed and assessment undertaken of those threats to the overall safety of the repository system. The kinds of questions that could be asked in relation to timeframe are not currently included in the methodology.

3.1.3 Radionuclide release pathways

The BIOMASS reference biospheres principally focussed toward the transfer of radionuclides in groundwater from geological disposal. Whilst the BIOMASS methodology was broader and did not exclude the gaseous or solid release of radionuclides, there was little discussion around these release pathways. Subsequent experience has shown that the BIOMASS methodology is also helpful in assessing near-surface and other types of disposal, for which gaseous and solid/erosional releases can be more relevant. There is now also more information and experience available in relation to these processes that would enable them to be more explicitly considered in the update.

3.2 SYSTEM CHARACTERISATION

The use of illustrations of site characterisations within assessments may be beneficial.

Characterisation of the system is an iterative process. From knowledge of the repository system, monitoring of a site can begin along with the development of a conceptual model of the biosphere. The site investigations produce data to address some parameters and to define other aspects such as biota present. Initial assessments can then identify additional data needs, essentially generating a list of data required from the site investigation programme. It may therefore be appropriate to include within the revision the suggestion that, whilst initially thinking about a site characterisation programme, a 'first pass' is taken through the methodology to identify those parameters and processes for which data may be required. There should then be continued iteration as data start to become available and the development of assessment models progresses. The context will change therefore from 'this is what we want to know about a site' to 'this is what is known about a site'. An iterative component should therefore be introduced at the beginning of the methodology, linking to the assessment context.

In characterising the system, a wide view should be taken of the surface system with that then described in terms of the components present. A balance needs to be achieved between the amount of information presented and the stage of the repository programme. FEP lists can be useful 'safety nets' for those new to the assessment process to ensure that important FEPs are not excluded without justification. The conceptual model of the site should be refined with new data as site characterisation programmes progress. Similarly, more refined models should be developed.

3.3 ENVIRONMENTAL CHANGE

There are many different processes and events that could threaten a disposal facility. However, it may not be necessary to look in detail at each. Where there are similar mechanisms of action then processes / events could be subsumed in a single assessment scenario. The relationships between events and processes, including feedback, can be represented within interaction matrices and consideration then given as to how to collapse the information into something sufficient for assessment purposes. Such an approach would help to maintain transparency. When deciding what should be assessed, thought should be given to the particular aspects that could affect dose. For example, transitions between different climate states need only be assessed if there is a mechanism by which increased dose may result.

When considering environmental change, feedback between different aspects of the system should be recognised. Interactions are not only unidirectional. For example, environmental change may affect human habits, but human habits can also affect environmental change, such as the construction of dams. Dam construction was included within the FEP lists with regard to changes to the hydrology of the system. However, how their construction feeds into landscape change was not discussed in detail. The human activities considered in an assessment should be proportional to technology. For example, if a large store is to be constructed on a site with near-surface waste disposal that has been forgotten about then it would be reasonable to assume that the technology would exist for surveys of the land to be undertaken that would identify the presence of the waste. It should furthermore be recognised that a facility would not be constructed if it could not cope with standard human behaviour and safety analysis in terms of the facility would have taken place in the very early stages of a repository programme. Either the facility would be located elsewhere, additional/alternative engineering would be incorporated into the facility design to mitigate against risks or an alternative type of facility would be constructed that was better able to maintain the required level of safety. Links should be made with the IAEA HIDRA project when considering future human actions.

Careful consideration is needed as to how to link to the work done in MODARIA I on climate evolution and environmental change. Climate has to be considered at a global level to ensure meaningful arguments are made. Global climate projections need to be downscaled to a regional / local context to allow the influence of climate on landscape change to be assessed. Both climate and landscape evolution have important inputs to near-field and geosphere components of safety assessments. Therefore, any consideration of climate and landscape has to be integrated across these components.

Whilst the potential for developing continuous projections of evolving global climate has been demonstrated in MODARIA I, it is recognised that a separate decision is needed on the way in which continually evolving climate is represented within a quantitative radiological assessment. A climate 'snap-shot' approach can still be applied, as discussed in results from the EMRAS II WG3 report, published as IAEA TECDOC 1799.

3.4 EXPOSURE GROUPS

Exposure groups was a separate and explicit section in the BIOMASS methodology. Experience, however, has shown that exposure groups have not been placed at such a high level in actual assessments.

As an overall approach, the information provided in BIOMASS is satisfactory, but there can be difficulties in defining how survey data should be used to support assessments and how to identify what is important in terms of behavioural assumptions. Some of these issues could be addressed by placing bounds on the system, such as physical constraints to the production of food stuffs or the number of people that can be sustained in an area. Examples could also be given as to how exposure groups have been considered in assessments. How to address the habits of people relative to future climate conditions also requires further discussion.

In assessing the exposure of people, the ICRP states that the focus for long-term repository assessments should be on adults. Deviation from this may however be necessary, for example to address the needs arising from public consultation or to address regulatory requirements. For those undertaking assessments for children and infants, consideration will be required as to the food habits and behaviours or those groups. There may therefore be merit in the revised methodology providing information around what information would be required to undertake assessments for other exposure groups. Experience has shown however that, unless there are very extreme habits, the food pathway is not too significant and examples could be included that demonstrate this point, as in the original BIOMASS methodology report. Therefore, in order to prevent over-complicating the methodology, examples for adults should continue to be used, but with discussion around this as necessary to address any differences arising as a consequence of age at exposure.

The suggestion was made that this step be moved from being a stand-alone step, to reflect experience in how people have addressed exposure groups within assessments. However, it was recognised that exposure groups are important in terms of communication, which may drive for the specification of exposure groups to remain a separate and distinct step, but with links provided to the arguments around exposure group habits and to ensure that physiological constraints are discussed. No final decision was made and further consideration may therefore be required as the update progresses.

3.5 PROTECTION OF THE ENVIRONMENT

There is an increasing requirement for assessments to demonstrate that impacts from a repository are acceptable both in terms of human and non-human biota exposures, the latter not having been explicitly considered in the BIOMASS methodology. As such, protection of the environment is a new aspect to be added to the methodology. It should therefore be noted in the revised methodology that the approach to the environment should be flexible to allow consideration of non-human biota exposures in addition to performing a human exposure assessment, depending upon national regulatory requirements.

The suggestion has been made that the methodology could be worked through in a human exposure context and then in a non-human biota context to identify whether there are particular differences that should be noted. This should not affect radionuclide transport, but may well affect the spatial scales and object delineation that is required for populations of biota versus human exposure groups. There could also be differences in assumptions around discharge areas. It may be that some discharge areas could be envisaged for biota population exposure that would not be appropriate for habitation by human communities.

Where there is a requirement to explicitly consider the exposure of non-human populations, the populations requiring protection and to be assessed should be decided at an early stage, in line with the interests of those commissioning the assessment, including who the intended audiences are. Managed stakeholder engagement may be an important factor in this regard to ensure that the populations selected cover those of public interest without focussing too much on detail – it is not feasible to explicitly assess all species that may be present in an ecosystem, particularly over long timescales and appropriate representative species should therefore be selected of relevance to a specific assessment.

There are currently no internationally agreed criteria for the protection of non-human biota, but a range of benchmarks are available, including the ICRP derived consideration levels[n]. In the absence of actual standards, there may be merit in providing examples of what has been done in assessments to date to demonstrate protection of the environment.

3.6 ASSESSMENT MODELS

More refined models should be developed as information and data are generated from site characterisation programmes and as knowledge is gained in moving through the different stages of repository assessments. Consideration should be given, when developing models, to the degree of discretisation required to ensure that spatial scales are appropriate for the physical dispersion of radionuclides within the system. Some thought has been given to this within the MODARIA I programme that could be used as input. Models should also be developed with thought given to extreme events

[n] For example, see BIOPROTA (2015). Scales for Post-closure Assessment: Scenarios (SPACE): Addressing spatial and temporal scales for people and wildlife in long-term safety assessments. Report prepared under the BIOPROTA international programme. Published by the Norwegian Radiation Protection Authority as StrålevernRapport 2016:2.

(e.g. erosion and sedimentation during storms) to allow for such events to be evaluated. System understanding is required therefore to inform on potential landscape change during extreme events and assumptions should be consistent between landscape effects and dose assessment.

Since the BIOMASS methodology was developed, considerable experience has been gained in the use of supporting models to both (i) interpret site characterisation information and (ii) to provide quantitative inputs required by radiological assessment models. There is therefore scope to provide greater discussion of the use of supporting modelling in the revised methodology.

3.6.1 Geosphere-biosphere processes

At some point in a disposal system there is a transition from radionuclides being transported in the geosphere to radionuclides being transported in the surface system. It is only when releases from the geosphere are known that biosphere work can be undertaken in earnest. There is no physical border, but there do tend to be separate assessment groups for the geosphere and for the surface system. The use of the term geosphere-biosphere interface can cause confusion and conceptual issues with people having different interpretations of this interface. Use of scientific terms for different parts of the system may alleviate these issues. Detailed discussion would be required to develop descriptions that are linked to real systems, but may be necessary to ensure that terminology is very clear within a common methodology.

Irrespective of the terms used, there are real processes that occur as radionuclides are transported from the geosphere to the surface system due, for example, to changes in redox conditions. Not all such processes are well known or well characterised.

The type and resolution of models used are important factors in assessments. For example, the discharge point to the surface environment will be affected by the resolution of the models employed. However, the exact location of a discharge point may not be so crucial in long-term assessments since biosphere objects tend to be defined by the catchment area within which a discharge occurs with mixing then occurring through that catchment. However, there is interest in undertaking more studies that will improve understanding of the transport of radionuclides from the bedrock to the surface and the processes that are important in governing radionuclide behaviour. The focus in this area should therefore be more on processes rather than the models that are employed, with multiple models potentially being employed to evaluate processes across this domain. Consideration should therefore be given to whether the methodology changes with regard to the processes occurring rather than on models.

Information from geosphere models needs to be closely examined in terms of both horizontal and vertical scales prior to biosphere modelling boundaries being defined. SSM are undertaking research in this area and the output could be fed in as the enhancement project progresses.

3.6.2 Geochemistry in soils and sub-soils and implications for modelling sorption

The transport of radionuclides will be affected by landscape processes, including landscape aging. Transport properties will therefore change over time even if the landscape itself is stable. There is therefore an important link between radionuclide transport modelling and the system identification and description.

In a project undertaken through BIOPROTA[o], an interaction matrix was developed that aimed to capture the key geochemical processes in the GBI. From this project, it is clear that consideration needs to be given to the key components and interactions and their appropriate aggregation; there is a tendency for lead-diagonal elements in matrices to be those aspects that can be readily visualised (e.g. soil, pore water etc.) rather than the key components of the system. Appropriate aggregation is necessary to ensure that interaction matrices are useful and provide the required links between key components in terms of processes and greater emphasis should be given to this in the revised methodology.

The behaviour of radionuclides in surface ecosystems is often represented using Kd values in combination with water flow. Whilst Kd is a simple means of representing sorption behaviour, there are a number of complicating factors, such as the amount of organic carbon present or the degree of farming intensity that will affect the nutrient and pH status of soils. The issue of parameter selection is a site-specific issue that largely focusses on present-day conditions, but soils will develop over time. As such, arguments have been made for the use of generic data. Alternatively, site-specific data could be applied with the database of generic data then being used to derive data ranges. The degree to which geochemical considerations will be required to be taken into account will largely depend on assumptions around whether near-surface aquifers are considered to be located in the surface system or in the geosphere domain. Consideration therefore needs to be given as to what can and should be said in terms of guidance for representing radionuclide geochemical behaviour in surface systems.

3.6.3 Special models for special radionuclides and processes

Within the system description section of the BIOMASS methodology, reference to specific radionuclides is not made and this is still considered to be the correct approach. Descriptions should be comprehensive in terms of processes and then decisions made within the model development stage with regard to models to represent those processes. When the radionuclide inventory is known, further consideration can then be given to the processes of importance for different radionuclides. Interaction matrices should therefore be comprehensive with regard to processes that could affect different radionuclides. To support this, lists could be provided that detail the different aspects of radionuclides that make them ‘special’, such as:

- multiple oxidation states;
- high bioavailability;
- interactions with organic matter;
- analogous to natural nutrients/ essential elements;
- close coupling to hydrogeological cycles;
- subject to microbial metabolism; and
- volatilisation potential.

[o] BIOPROTA (2014). An Exploration of Approaches to Representing the Geosphere- Biosphere Interface in Assessment Models. December 2014. Available from www.bioprota.org.

The processes associated with ‘special’ radionuclides do not change the overall methodology, but can provide some commentary on methodological application and/or provide input to site characterisation requirements. It may not always be the case that special models will be required to address these radionuclides. In some instances, it may be that special data may be needed to represent behaviour within overall assessment models.

The different processes associated with ‘special’ radionuclides should be captured in FEP lists and commentary added to explain that decisions may need to be made for each element of interest as to whether detailed process representation is required or whether a simplified approach to representing the behaviour can be applied. The inclusion of all processes in FEP lists will help to ensure that processes are considered with regard to individual elements rather than just those for which the process is commonly known. An example would be the volatilisation of chlorine in addition to carbon and selenium. Discussion of processes in relation to the radionuclides of interest is not a topic that is well covered in BIOMASS. However, there is now experience from having undertaken assessments that can be used as examples to highlight important processes that could be the basis for a useful addition to the methodology. Examples could be provided that illustrate the importance of specific processes for certain radionuclides in particular contexts.

Special models have been used to support assessments, but the focus has been on processes in relation to long-term release in groundwater. Further consideration is needed as to whether different models would be required for alternative release mechanisms, including pulse releases. For such releases, it may not be appropriate to talk in terms of averages, but rather short-term non-linear processes may occur. The appropriate averaging procedure to represent these processes within long-term assessments requires further thought. Furthermore, thought should be given as to whether equilibrium models can be applied, but with alternate time-averaging of input data or whether greater model discretisation is required for shorter-term releases.

3.6.4 Addressing uncertainty and correlations

There are many different uncertainties associated with long-term dose assessments for repository systems, including model uncertainty, parameter uncertainty and process uncertainty. The report arising from WG6 of MODARIA I includes information on model and system uncertainty, including good definitions relating to uncertainties. The NEA also has a group on uncertainty in safety case systems. It is important therefore that duplication is avoided, but information should be provided on how different scenarios can be used to evaluate uncertainty into the future; the future is uncertain, but uncertainties can be narrowed with regard to physical constraints, for example on shoreline displacement. Examples could be provided on how parameter and model uncertainty can be evaluated in assessments.

Uncertainty in assessments can occur as a result of lack of process understanding. The use of alternative conceptual models and use of special models for radionuclides (see Section 3.6.3) can help in capturing such uncertainties and this should be included in the revised methodology.

Biosphere assessment is one aspect within the overall safety case for a repository and care should be taken to ensure that the biosphere is not treated in isolation. However, the biosphere is a measuring instrument rather than a safety barrier and uncertainty may not be treated in the same way as in the rest of the safety case. Thought needs to be given as to when it is appropriate to consider uncertainty in assessments and when it is not appropriate. Probabilistic modelling can be used as a tool to evaluate uncertainty. The use of probabilistic models does not remove uncertainty in models, but does allow for identification and evaluation of the main uncertainties and the influence these have on the assessment. Care should however be taken when applying probabilistic models since some processes will be linked.

3.6.5 Balancing complexity and transparency

The need to balance complexity and transparency was not explicitly discussed in the BIOMASS methodology, although the whole approach is aimed at ensuring that models are fit-for-purpose. Maintaining an appropriate balance between complexity and transparency is always a challenge in modelling and it would therefore be useful if some guidance could be provided, based on experience of undertaking assessments.

Where sets of models are used in assessments, abstraction of data from one as input to another is often required. Abstraction is a form of simplification, allowing detailed processes to be evaluated at an appropriate level in overall assessment models. Again, guidance on what might be better to explore in detailed process models and how to extract data from these models as input to another whilst maintaining transparency was not explicitly discussed in the BIOMASS methodology.

The BIOMASS methodology is good with regard to overall transparency in assessments through the use of FEP lists and maintaining records on FEP exclusions, but additional aspects could be added. For example, the need for communication to identify issues during the planning stage of assessments, to help alleviate the risk of issues arising during the assessment process. The more that is known about a site, the more issues will be identified and there will therefore be iteration throughout. However, identifying stakeholder concerns at an early stage will help to mitigate some of these issues.

3.7 MEASURES FOR CONFIDENCE BUILDING

The IAEA and NEA have produced documents on confidence building for safety cases in general that involve stage-gated approaches whereby, at the conclusion of each stage of assessment, review is undertaken and stakeholders engaged prior to progressing to the next stage of assessment. The use of multiple lines of reasoning is also included as a means to building confidence in assessments, such as the use of different endpoints and different lines of argument in assessments. Alternative conceptual models could also be developed that address different opinions on processes or alternative scenarios evaluated.

In considering whether the BIOMASS methodology should be revised to account for confidence building measures, it was suggested that the methodology be reviewed in light of current knowledge and experience. Thought would then be needed as to how much confidence building should be explicitly discussed in the revised methodology and when it would be more appropriate to reference out to other sources of information. For example, a number of model validation exercises have been undertaken through the BIOPROTA forum with reports available that illustrate the benefits of such exercises to build confidence in different assessment models. It is unlikely to be appropriate to include all the information from these exercises, but reference could be made to illustrate how such exercises can be used to build confidence.

The use of analogues can also help to build confidence in assessments. For example, Posiva have used studies on reference lakes and mires to derive data for the types of ecosystems that may form over time around Olkiluoto as new land areas emerge as a result of post-glacial land uplift. Chemical analogues may also be useful, enabling models to be evaluated in terms of their ability to represent the transport of non-radioactive elements through and between system components. Human behaviour analogues could also be applied to demonstrate behaviour under different climates or as a result of different assumptions for agriculture etc.

Consistency in assumptions between different assessments can also be an important factor in building confidence, particularly in relation to assumptions around climate evolution. Work undertaken in MODARIA I provides important information for longer term climate change, but consistent assumptions are also required for shorter timescales (of the order of hundreds to thousands rather than tens of thousands of years). Discussion around this aspect should be included under the assessment context in the revised methodology. Discussion could also be provided in how to apply the methodology to undertake assessments in the shorter term (i.e. operational and initial post-closure phases).

3.8 CHEMICAL HAZARDS

There are increasing requirements for assessments to consider not only impacts from radionuclides, but also those from other chemical hazards associated with radioactive wastes and engineered barriers. The chemical hazards will largely depend on the type of repository and the wastes disposed of. Irrespective, there is currently a lack of harmony in the way that chemical and radiological hazards are assessed. A project is currently underway within BIOPROTA on this topic that is due to conclude in 2016 and could provide useful input.

The degree to which this is included in the revised methodology requires further consideration. It may be appropriate to include mention of this topic in the revised methodology as an area of interest and provide some brief information on how the topic can be addressed (e.g. use of consistent transport models), but acknowledge that the methodology has not been designed for the evaluation of chemical hazards, with endpoints potentially differing for the various hazards.

3.9 METHODOLOGICAL ILLUSTRATIONS

The BIOMASS methodology includes example 'reference biospheres' that demonstrate how the methodology can be applied. With several assessments having now been completed, both site-generic and site-specific, real examples could be provided that show how the method has been applied. Examples from a range of different assessments could be provided to prevent focus on just one site or assessment, and to provide illustrative examples of the different levels of complexity of assessments and models as repository programmes develop. The examples should again be provided as appendices to the main methodology to ensure that the steps to undertaking assessments remain concise.

The sites / assessments that could be used to illustrate the methodology include:

- SKB studies in Greenland for cold climate conditions;
- Forsmark in Sweden (used within WG6 of MODARIA I) for marine / coastal domain assessments;
- Olkiluoto in Finland for landscape development;
- Yucca Mountain as a prescribed system;
- Andra assessments for temperate inland sites and consideration of warmer climates;
- LLWR assessments for near-surface disposal systems; and
- RWM site-generic assessment work.

A systematic approach to selecting examples should be taken, with decisions made according to the methodological step and objectives for what is to be illustrated. More than one example may be appropriate to illustrate steps at different stages of repository programmes (e.g. site-generic versus site-specific). The use of ensembles of models in assessments should also be illustrated.

The 'reference biospheres' in BIOMASS were all terrestrial. No marine / coastal examples were provided and this is an important omission. Both generic and site-specific examples are now available (e.g. work undertaken by RWM and by LLWR, SKB and Posiva) that would help to illustrate the methodology for coastal systems where shoreline processes are particularly important, both in terms of landscape evolution (new land areas and erosional processes) and salinity interface effects.

4. KEY AREAS FOR REVIEW AND UPDATE OF THE BIOMASS METHODOLOGY

From the presentations and discussions, the following key points are proposed to be addressed or incorporated within in the enhanced methodology.

- The context of the BIOMASS methodology within the broader safety case should be emphasised, linking back to IAEA Specific Safety Guide SSG-23[p].
- There is a need to consider the system as a whole to ensure that assumptions and applied parameters are consistent throughout (i.e. from the near-field, through the geosphere to the biosphere) and for processes in the biosphere that influence the release and transport of radionuclides in the geosphere to be appropriately captured and represented. Consistent assumptions will help reduce overall uncertainty in assessments.
- Provision of information and discussion around habit assumptions (e.g. ingestion rates) and the need to consider the physical constraints of the system relative to human behaviour assumptions to avoid overly conservative assessments. Habit surveys should also focus on the type of community of interest, such as coastal communities that may have higher fish consumption rates than those reported in averaged national statistics. Consideration should also be given to those habits that will not be captured through habit surveys such as illegal fishing or poaching, which could give rise to higher exposures through obtaining a greater proportion of diet from local sources.
- There is a need to ensure that any lack of continuity in habit assumptions arising from survey data is carefully explained to ensure transparency throughout the assessment completed to support the different stages of repository development.
- The BIOMASS methodology focusses on the development of radiological assessment models and does not discuss to any great extent how supporting models, such as landscape or process models, should be developed. The methodology includes little on how the data from supporting models can be extracted and used in the overall assessment, although some examples of supporting calculations are provided. There may therefore be merit in providing more explicit examples as to how such models can be deployed in assessments.
- There is variation observed in the degree of sea level rise assumed in assessments as a result of global warming and loss of continental ice. A common strategy on such assumptions would be beneficial to avoid arbitrary differences between assessments. Efforts should also be made to ensure that assumptions as to global climate on both short and long timescales are consistent across assessments.
- It should be made clear in the enhanced methodology that there are correlations between parameters that need to be understood when developing assessment models to ensure that realistic combinations of parameters are included.

[p] The safety case and safety assessment for the disposal of radioactive waste. IAEA Specific Safety Guide SSG-23. Available from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1553_web.pdf.

- Examples of the type of question that should be asked with regard to assessment timeframe should be included. These should relate to processes or events that may pose a threat to the safety of the disposal system or affect the behaviour of radionuclides throughout the overall assessment timeframe.

- Consideration should be given to terminology with the suggestion made that, rather than using the term ‘biosphere’, the term ‘surface ecosystem’ could be used. This would help move away from issues around interfaces with other parts of the disposal system. The system identification and justification step should then make clear what is intended in terms of surface ecosystem and dose modelling. The EMRAS II, WG3 report may provide useful input.

- Approaches for explicitly assessing protection of the environment have developed significantly since the BIOMASS methodology was developed. The overall approach to evaluating radionuclide transport through the environment should be flexible to allow consideration of non-human biota exposure in addition to human exposure assessment, depending upon national regulatory requirements. Differences may arise with regard to spatial averaging of radionuclide contamination across ecosystems for populations of biota and in assumptions around discharge areas. There may be merit in including examples of how environmental protection has been demonstrated in assessments, including the selection and representation of species in assessments and the application of available benchmarks.

- Illustrations of the application of the methodology should, where possible, draw on actual assessments that have been undertaken rather than using ‘reference biospheres’, with illustrations being provided, as appropriate, to illustrate application at different stages of repository programmes, such as site-generic versus site-specific. The examples, and the associated discussion, should illustrate that, when at a generic stage of assessment, assessors should avoid going into too much detail to avoid pit-falls. The assessment models should remain flexible to allow ready development once a site has been selected and data and knowledge of that site are generated. Illustrations should also cover the use of ensembles of models, such as the use of landscape and process models to support dose assessment models. Illustrative boxes could be used throughout the main report to provide examples of different aspects of the methodology.

5. FORWARD BIOPROTA WORK PROGRAMME

An interim WG6 meeting will be held in combination with the next BIOPROTA project workshop, from 10-12 May 2017. The meeting will take place in Brugg, Switzerland, hosted by ENSI.

The BIOPROTA project technical support team will undertake a number of tasks prior to the 3rd project workshop. Those tasks will be presented for discussion during the workshop. The main enhancement areas for the methodology are illustrated in Figure 5-1.

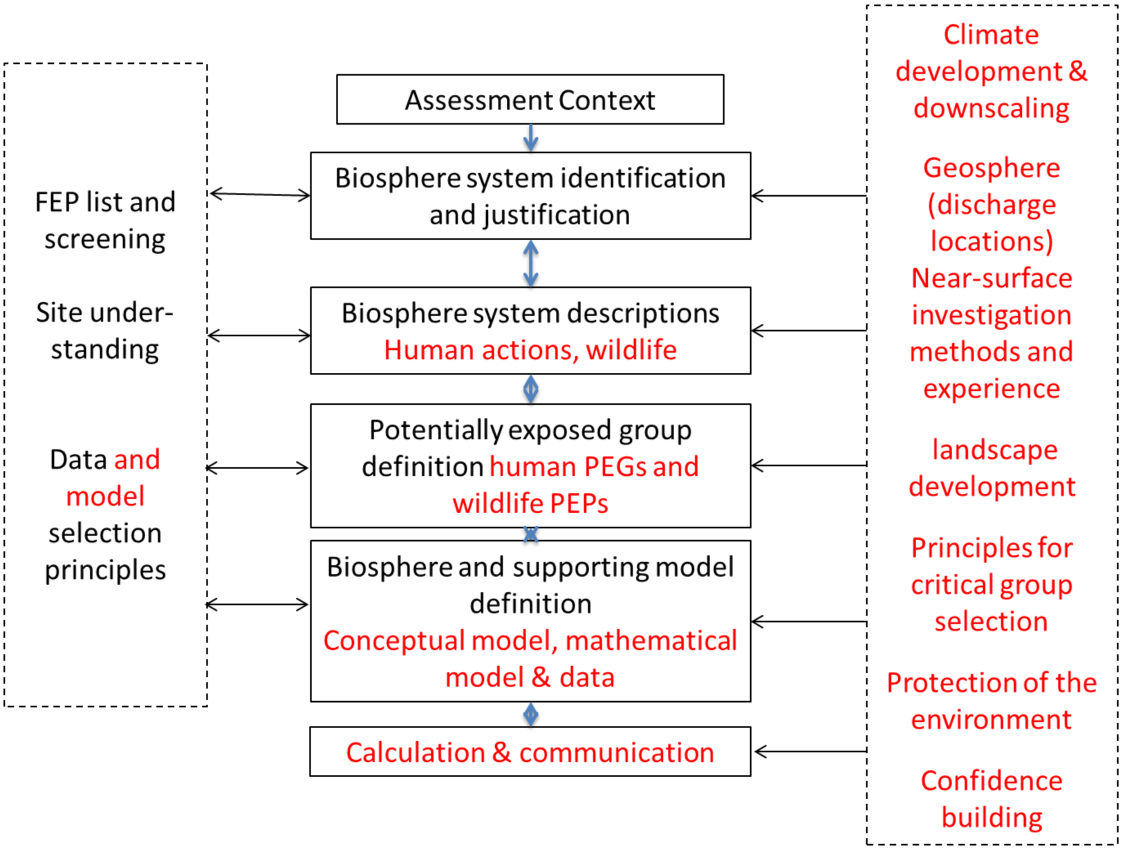

Figure 5-1. Steps in the BIOMASS methodology and supporting information, illustrating proposed enhancement areas (red text).

The tasks to be undertaken by the BIOPROTA technical support team prior to the 3rd project workshop are as outlined below.

- Undertake a review Section B of the BIOMASS methodology to revise language in line with suggestions made during the 2nd project workshop and identify where, within Section B, the new information requirements listed in Section 4 would fit.
- Develop text to describe biosphere assessments in the context of the overall safety case.
- Draft text around site characterisation as a lead in to site understanding and how previous assessments can be used to identify focus areas.

- Develop principles for critical group selection for discussion during the third project workshop.
- Develop a section relating to the definition of potentially exposed groups to include potentially exposed wildlife populations.
- Supplement information on site characterisation to address characterisation and data needs in support of non-human biota dose assessments.
- Develop material on confidence building, drawing upon information produced by WG6 of the first MODARIA programme and identifying examples that could be used for illustration.
- Review information on FEP lists and screening to ensure appropriate connections are made to site understanding and develop text around interaction matrices and the development of conceptual models.
- Develop data and model selection principles for discussion.

APPENDIX A. MEETING PARTICIPANTS

The workshop was attended by the following participants, ordered alphabetically by organisation

Participant	Organisation
Lise Griffault	ANDRA, France
Mathew Johansen	ANSTO, Australia
Gu Zhijie	China Institute for Radiation Protection, China
Ari Ikonen	EnviroCase Oy, Finland
Leena Torpo	Fennovoima, Finland
Graham Smith	GMS Abingdon Ltd, UK
André Ruebel	GRS, Germany
Branko Kontic	Jozef Sfen Institute, Slovenia
Kyung-Suk Suh	KAERI, Korea
Hyosooh Jung	Korean Institute of Nuclear Safety, Korea
Alex Proverbio	LLWR, UK
Jeff Whicker	Los Alamos National laboratory, USA
Mike Thorne	Mike Thorne & Associates Ltd, UK
Andreas Poller	Nagra, Switzerland
Keiko Tagami	NIRS, Japan
Esther Phillip	Nuclear Malaysia, Malaysia
Lauri Parviainen	Posiva Oy, Finland
Russell Walke	Quintessa Ltd, UK
Karen Smith	RadEcol Consulting Ltd, UK
Ray Kowe	RWM, UK
Lieve Sweeck	SCK·CEN, Belgium
Emma Johansson	SKB, Sweden
Ulrik Kautsky	SKB, Sweden
Tobias Lindborg	SKB, Sweden
Maria Norden	SSM, Sweden
Shulan Xu	SSM, Sweden
Tarmo Lipping	Tampere University of Technology, Finland
Jari Turunen	Tampere University of Technology, Finland