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

Summary of the third workshop held in parallel with the first interim meeting of MODARIA II Working Group 6

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Version 2.0, 18 September 2017

PREFACE

BIOPROTA is an international collaboration forum that 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 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 provides a summary of the presentations and discussions during a technical workshop of the BIOPROTA project to review and enhance the IAEA BIOMASS methodology. The workshop was hosted by ENSI in Brugg, Switzerland from 10-12 May 2017. This was the third workshop of the BIOPROTA project and was aimed at presenting the on-going work programme and further developing the work programme for activities in 2017. The workshop was held jointly with the first interim meeting of Working Group 6 of the IAEA MODARIA II programme. The objectives of WG6 are similar to those of the BIOPROTA project, and the two projects met together for the second time 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.

Version History

Version 1.0: Draft workshop report prepared by Karen Smith (RadEcol Consulting Ltd) based on participant contributions and reviewed by Russell Walke (Quintessa Ltd), Mike Thorne (Mike Thorne and Associates Ltd) and Graham Smith (GMS Abingdon Ltd) prior to distribution on 3rd August 2017 to workshop participants and BIOPROTA project sponsors for comment.

Version 2.0: Final workshop report prepared by Karen Smith (RadEcol Consulting Ltd), taking account of comments received from workshop participants on the version 1.0 report. Distributed to workshop participants and sponsors on 18 September 2017.

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1. INTRODUCTION

The 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 that present a range of radiological and radio-ecological characteristics (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 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 support a wide range of 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 of 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 was initiated in 2016 that was to run for two years. The project is 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 in April 2016 provided a

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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.

first opportunity to present and discuss experience and suggestions for methodological improvements[d]. A second workshop was then held in combination with the first Technical Meeting of Working Group 6 (WG6) of the IAEA MODARIA II programme in October-November 2016 at which enhancement activities were assigned to the BIOPROTA project TST[e]. This report provides a summary of the third workshop, held together with the first interim meeting of WG6, at which progress with activities was presented and WG6 participants provided additional input on topics for the BIOMASS enhancement.

1.1 AIMS AND OBJECTIVES

The overall aim of the 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 workshop were:

- to present progress on agreed activities following the autumn 2016 project/WG6 meeting;
- to hear from a wide range of organisations about their on-going interests in this area; and
- to agree on next steps for the BIOMASS methodology enhancement, including the assignment of tasks to the BIOPROTA project TST.

1.2 WORKSHOP PARTICIPATION

The workshop, hosted by the Swiss Federal Nuclear Safety Inspectorate (ENSI) in Brugg, Switzerland, was attended by 31 participants from 13 countries, representing a range of operators, regulators, researchers and technical support organisations. Participants are listed in Appendix A.

1.3 REPORT STRUCTURE

Section 2 of this report summarises the presentations made by the Technical Support Team (TST) and other participants on enhancement areas. Section 3 then summarises feedback from break out discussion sessions. Forward actions are then detailed in Section 4.

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[d] BIOPROTA (2016). Update and Review of the IAEA BIOMASS-6 Reference Biospheres Methodology. Report of the first programme workshop held 20-22 April 2016, hosted in Brussels by FANC, Version 2.0.

[e] BIOPROTA (2017). 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 held 31 October to 4 November, hosted in Vienna by IAEA, Version 2.0.

2. SUMMARY OF PRESENTATIONS

Brief summaries of the presentations from participants are provided below, along with key discussion points.

2.1 WELCOME REMARKS AND SCENE SETTING

2.1.1 Biosphere modelling and Swiss site selection process

Felix Altorfer (ENSI) opened the workshop with a presentation summarising current activities at ENSI with regard to radioactive waste disposal.

A review of Nagra documentation providing a sectoral plan for site selection has recently been concluded. This plan sets out the rules for how the public can be involved in the site selection process and the rights for towns and their populations. A public consultation is about to begin and will run until the end of 2018. Four key safety criteria have been defined and site selection must be justified according to these criteria. Design principles have also been set. These require climate and landscape evolution to be considered since the Alps, a geologically active area, are nearby and the implications of erosion etc. must be taken into account over an assessment timeframe of 1 million years.

The site selection process in Switzerland is comprised of 3 stages, with stage 1 considering the whole of Switzerland to identify regions of potential interest (stage 2). Site selection is then stage 3. Stage 2 has been completed with 6 regions of interest being initially identified and subsequently narrowed to 3 areas of interest, all of which are close to the German border. All sites are relatively closely located and hence climate variation between the sites will be minimal.

Any interested party can take part in the consultation process and in the technical forums on safety that are held four times per year. All questions and responses are published on the internet. Particular concerns have been raised about the potential implications for thermal springs and drinking water in the region, since several spa towns are present. To date, over 140 questions have been submitted and responses given. There is follow up to ensure that questions have been answered to an appropriate level. With potential sites being located close to the German border, a German expert group will be invited to provide opinions on the plans.

The approach described provides a good example of engagement with stakeholders. By engaging the public, acceptance is greatly aided. The overall site selection process began in 2005 and aims to be completed with a political decision by 2030. A national referendum is then likely to be held on the overall decision.

2.1.2 Introduction to MODARIA II Working Group 6

Gerhard Pröhl (IAEA, Scientific Secretary for MODARIA II) followed with an introduction to the joint MODARIA II working group 6 (WG6) interim meeting and BIOPROTA project workshop. The joint working between BIOPROTA and WG6 provides a good opportunity for mutual discussion and for sharing views.

Biosphere modelling has been a long-term issue at the IAEA with several programmes having been run over the years to improve modelling capabilities. A big difference can be seen if current biosphere modelling approaches are compared against those available during earlier programmes, with much more detail being evident in current models to take account of aspects such as landscape change and to address issues around radionuclides with particular behaviour.

The MODARIA II programme began in November 2016. WG6 aims to revisit the BIOMASS methodology that was published in 2003 and to enhance this, taking into account new knowledge and experience. Ideally, as many Member States as possible should participate to capture experience from different programmes that are at different stages.

The IAEA is also cooperating with the EU on a nuclear safety inception programme, PAGODA 2, which started in 2017 and will run for 4 years. One project within this is focussed on radioactive waste management and will address the lifecycle management of radioactive waste, including emergency responses. One of the objectives is to develop and disseminate robust and coherent models that allow the assessment of radioactive impacts from waste disposal, taking account of different timeframes according to the characteristics of the wastes to be disposed. It is intended that information from the MODARIA II WG6 programme can be used to support this.

2.1.3 Progress to date on the BIOPROTA project to enhance the BIOMASS methodology

Russell Walke (BIOPROTA TST) gave an overview of the BIOPROTA project, including a summary of the BIOMASS methodology. The BIOPROTA project aims to take account of developments in assessments and new knowledge and experience from undertaking long-term biosphere assessments leading to an enhanced methodology. It should be noted, however, that the BIOPROTA programme is due to run until the end of 2017 with a standalone report being prepared as input to MODARIA II WG6. Further enhancement activities will be required to be undertaken within WG6 from 2018.

The BIOPROTA project has delivered two workshops, the first being held in Brussels in April 2016 at which presentations were made by the TST and other workshop participants on topics including:

- climate and environmental change;
- geosphere-biosphere interface;
- protection of the environment;
- site investigation and characterisation; and
- examples of the application of the BIOMASS methodology.

A second workshop was then held jointly with the first technical meeting of MODARIA II in Vienna in October/November 2016 at which there were further presentations from the TST and other participants plus substantial discussion around subjects including:

- practical experience of biosphere assessments: SKB, RWM, ANDRA;
- considerations for near-surface facilities;
- Posiva's biosphere programme and terrain modelling;
- regulatory review and independent modelling; and
- warm and cold climate hydrology.

Both workshops have been documented in substantial reports that are available from the BIOPROTA website. In addition to the presentations and discussions, potential enhancement areas were identified and tasks assigned to the BIOPROTA TST for delivery under 2016 project funding. Progress on BIOPROTA project enhancement areas are summarised in TST-delivered presentations below.

Lessons learned from assessments undertaken to date should be extracted and used to enhance the methodology, ensuring the focus is on providing pragmatic advice for proportionate assessments.

The BIOPROTA project deliverable will be in the form of an interim report on enhancement activities that have been undertaken in cooperation with the IAEA. A glossary of terms will be needed for the enhanced methodology to help ensure common understanding.

2.2 CLIMATE AND LANDSCAPE DEVELOPMENT

2.2.1 MODARIA I WG6 climate development and downscaling

Tobias Lindborg presented an overview of the work undertaken by WG6 of the IAEA MODARIA I programme on climate and landscape modelling, specifically looking at global climate modelling and downscaling to regional climate and landscape developments from which processes that could have an impact on dose modelling can be identified. Climate and climate change can trigger landscape processes, particularly in coastal regions affected by previous glaciation events. The geological context of a site and facility will determine the timescales of relevance for assessments that will, in turn, determine whether long-term global climate projections are needed to inform site evolution over time. The facility type is an important consideration with different facilities that are co-located potentially having different narratives. There are also various climate drivers in addition to carbon dioxide that could result in several climate narratives being appropriate for a single site. The climate narratives inform landscape development studies.

The work of WG6 of MODARIA I is an important component for the update to the BIOMASS methodology, feeding into various aspects, including analyses of relevant features, events and processes (FEPs). Tobias noted that it would be good to include the RWM work in support of MODARIA I WG6 on how global climate can be downscaled to inform on local climate as an illustration within the updated BIOMASS methodology. It would also be useful to refer to organisations with broad competencies in this field.

In updating the BIOMASS methodology, note should be made that it is not only future climate that may be of interest; historic data can also be applied to demonstrate the performance of the system, particularly in earlier programme stages where a site may not have been selected. Historic data can also be useful in terms of projections of future site conditions by taking account of what has happened at a site in the past. Climate information can also help to inform what needs to be assessed. Future climate projections are not to be treated as predictions, but rather as examples of how a system could evolve. Information about climate should be abstracted for use in assessments and can be used to identify aspects that should be assessed further, such as focusing on post-glacial phases rather than periods when ice sheets are present.

The MODARIA I WG6 report has been completed to the satisfaction of participants and submitted in 2016 to the IAEA for publication Several papers relating to the work have been published and are available for referencing in the interim. The climate emulator used in support of the RWM work is in the public domain and its use by others is encouraged to help explore uncertainties.

2.2.2 Landscape development at Olkiluoto

Lauri Parviainen gave a presentation about work undertaken by Posiva on landscape development modelling at Olkiluoto Island in Finland, which has been selected as the site for a spent nuclear fuel repository that is now under construction. Disposals are planned to start in 2024, which will reflect the culmination of more than 40 years of work to achieve that milestone.

Olkiluoto Island is subject to post-glacial land uplift, with the current rate of uplift being around 6 mm per year. Continued land uplift will result in new land areas and freshwater bodies developing. It is assumed that future land use will be unchanged from that at present. A land uplift model has been developed and recently updated. The updated model allows uncertainty around the exact location of water bodies to be considered. The model is supported by a variety of data sets, including detailed radar measurements of land areas. Data regarding the sea bed were relatively limited, and were such that uncertainty increases with distance from the coast, resulting in inferred quite uniform future terrestrial landscapes in these regions, because small-scale heterogeneities were not fully represented in the limited data sets available. Soil stratigraphy has been characterised both around the island and at nearby reference areas and is used to inform the type of biospheres that could occur in the future. Different climate cases are used to support the precipitation data that are then used, in turn, to calculate flow data for rivers.

A range of processes need to be taken into account when considering how the landscape might evolve. These include sedimentation, erosion, peat growth, lake ingrowth, land use and development of water bodies. Water bodies have been modelled by conventional GIS analysis of flow accumulation, with river discharge being modelled using site-specific precipitation data. Lakes are formed on areas where water can accumulate with the height of lake water determining whether or not it will be a lake or peat bog. The occurrence of reed beds is dependent on fetch distance, water level height, flow rate and shelter from waves. For mires, the minimum size is stipulated as 0.5 ha and they are not permitted to form on agricultural land areas. In the 2012 biosphere assessment, erosion and sedimentation rates were constant and depended on the land use type and surface soil type; these data are now in the process of being updated. Cropland locations are defined by the presence of suitable soil types, slope and the amount of solar radiation.

Discharge locations from the repository are projected to vary only slightly over time. Biosphere 'objects' for assessment are chosen once release locations are identified. The biosphere objects to be modelled are then chosen according to certain criteria, such as potential for contamination by irrigation, potential for direct geosphere release, and surface hydrology characteristics. Each object can vary over time as landscape change continues. All aspects of the terrain and ecosystems development modelling are described in Posiva report 2012-29.

In undertaking assessments, it is important to consider a range of potential exposure scenarios, including use of a groundwater well, in addition to accumulation of radionuclides in mires and later use of the mire as agricultural land. There is the possibility that alternative discharge locations may be identified (e.g. as a result of permafrost) or new assessment endpoints need to be evaluated, such as the exposure of non-human populations.

When updating the BIOMASS methodology, it will be important to capture landscape change, but care must be taken not to prescribe the use of changing landscape models in assessments, as they will not be appropriate in all situations. The local context must be taken into account in assessments and this should be highlighted in the methodology. All assessments should include consideration of whether landscape change needs to be addressed. Screening is not a word used much within BIOMASS, but needs to be brought out more in terms of evaluating what needs to be included in assessments and what can be excluded. Checks should be made throughout the enhanced methodology to ensure that prescriptive words such as 'must' are not used.

2.3 SITE CHARACTERISATION

2.3.1 Site characterisation in support of assessments

Mike Thorne (BIOPROTA TST) presented.

BIOMASS concentrated on biosphere system description, but did not include much detail on how the biosphere at a specific site should be characterised through site investigations. This resulted in part from the historical view that there could be a 'reference biosphere' that could apply to all assessments as a measuring instrument. That view has changed, with the biosphere being recognised as an integral part of the overall system. There is now considerable experience available internationally on site characterisation. Integrated site characterisation programmes have and are being undertaken by organisations such as Posiva, LLWR, SKB and Andra. Experience has also been gained in the development of site assessment models from the resulting site characterisation data. Site characterisation is multi-disciplinary and it has been found useful to generate discipline-specific descriptions, which are then integrated within an overall site-descriptive model. It therefore makes sense to develop biosphere system descriptions that structurally mirror how the system is conceptually envisaged, such as solid geology, soils and sediments, hydrogeology, surface hydrology, geochemistry, biota, atmospheric characteristics and climate.

Iteration is an important component of site characterisation. Site characterisation is not a once-only process, but needs to be continuous and run in parallel with assessments with feedback in-between. The level of detail required will depend on the reasons for undertaking the characterisation programmes and the stage of the repository programme. Site characterisation begins at generic assessment stages and runs through the operational phase until the facility is closed. This is not a factor that was previously clear in the BIOMASS methodology. Furthermore, the fact that the area to be characterised may be much larger than the area of direct relevance for the facility was also not emphasised. The use of a larger area helps to ensure that all relevant information at the regional level is captured and to allow features that could be present in future landscapes to be incorporated that are not present in the current landscape. Where climate change has the potential to have a large impact at a site, it may also be appropriate to consider analogue sites, although the level of detail may not be so great as for the site itself since it is to inform on post-closure assessment conditions that are substantially different from today, which cannot be known in detail.

The typographical approach to biosphere system classification that is advocated in the original BIOMASS methodology appears to support a 'top-down' approach. However, site characterisation programmes, such as that of Posiva, have taken a more 'bottom-up' approach where multiple measurements are taken, with decisions only then being made as to how the information should be structured. This type of approach has been considered more useful than starting with 'shopping lists' of the data required. Typographical approaches can then be useful for reclassifying field and other data into assessment categories once site characterisation programmes are underway.

2.3.2 Experience with biosphere characterisation

Ari Ikonen presented personal views on experience with site characterisation whilst working at Posiva.

In the 1970's site selection studies began that lasted to the end of the 1980's, supported by readily available information rather than doing any actual characterisation studies for the biosphere. The final pre-site selection studies then focussed on bedrock and societal/logistic conditions and earlier biosphere work was omitted in favour of a drinking water well dose indicator. However, following site selection, it was recognised that a well pathway was not always the most conservative and regulatory requirements were introduced that required the consequences of land uplift to be taken into account along with exposure of biota. Initial characterisation activities were also beginning from the viewpoint of environmental impacts from construction activities. Then, in the mid-2000's the regulator called for site knowledge to be the basis for building a safety case and to support model development. The first landscape development modelling was completed in 2006, which made clear the need to focus characterisation work on features that were not currently present at the site, but that could be present in the future such as mires, lakes and rivers. As such, a reference area was selected that provided reasonable examples of what might be present in the future.

The steps used to describe the biosphere followed, in a broad sense, the BIOMASS method, although some aspects were considered messy and tedious to understand and apply. Once site characterisation work was underway, the site understanding became the basis for model development and dialogue is required between biosphere experts and model developers. A 'top down' approach is considered less appropriate than a 'bottom up' approach since the former may fail to identify all important aspects of a site from an initial generic viewpoint. It is also important to avoid trying to squeeze a site into an existing model. Whilst it may be workable at a practical level, it is likely to pose a high risk of stakeholder issues arising. Ultimately, a site should tell the story and, when moving from site-generic to site-specific assessment stages, a change in thinking is required. Early on, consideration should be given as to what is the site in terms of spatial and temporal contexts, which will help to ensure that characterisation programmes are representative.

SKB has had similar experience to that of Posvia with regard to site characterisation programmes, particularly regarding the importance of site understanding in the development of assessment models and for stakeholder communication. For Andra, there is a regulatory requirement for detailed initial state understanding to be demonstrated. National regulations can therefore affect what is specifically required in terms of site descriptions and characterisation programmes. Scientific development can also influence requirements, as can alternative assessment endpoints.

2.3.3 Human factors

Graham Smith (BIOPROTA TST) noted that human community types were recognised as part of site characterisation within BIOMASS and that Table HI of the methodology provides details of human community types and their activities relative to the amount of trade and biosphere controls that were based on recognised communities. Consideration should be given during the methodology enhancement activities as to whether this table is still relevant. Consideration also needs to be given to future human actions, including land use, which is also linked to environmental change.

The IAEA HIDRA project addressed inadvertent human intrusion in the context of safety cases and decision making during the lifecycle of a disposal facility, taking into account societal factors. Intrusion issues were not considered in isolation, but as part of an integrated approach. The output from the HIDRA project could provide useful input to the enhanced methodology. Societal assumptions are part of the assessment context and this section should be reviewed to consider whether updates would be appropriate.

Assumptions for human communities do not have to be the same throughout assessments, but should be coherent. SKB report TR-14-08 considers FEPs related to future human actions and their screening for further consideration in post-closure safety assessments, the selection of representative future human action scenarios and their analysis. Analogue sites were used to reflect assumed changes in conditions at the site and the current range of technical development at these analogue sites used to reflect what could be possible at the site in the future. This report could again provide useful input to enhancement activities, illustrating an approach that has been taken to address the issue of future human actions.

2.3.4 Biosphere system identification and justification – Andra’s example of climate development

Lise Griffault presented the approach taken by Andra to considering climate development in the safety assessments for planned (Cigéo) and operational (CSA) radioactive waste disposal facilities in France. The French Nuclear Safety Authority has called for biospheres that are representative of particular climate states that might exist in the future (up to 1 million years for Cigéo and 10,000 years for CSA) to be defined. Andra’s approach to addressing this requirement has been to select typical biospheres for which climatic conditions could exist based on simulations of climatic and geomorphological evolution at the sites. The approach has been discussed with the safety authority and the BIOMASS methodology was found to be very useful in those discussions, particularly in illustrating what is suggested as an approach internationally.

The Cigéo facility is intended to be located at around 500 m depth in clay rock overlaid with sedimentary rock at an inland site. The facility will be for the disposal of medium to long-lived waste from reactor decommissioning and vitrified waste from fuel reprocessing. For each biosphere type that could occur at the site over the next million years, the geological, hydrological and ecosystem evolution are considered. Climatic and geodynamic simulations and a bio-geoprospective study were used to define the plausible types of biospheres. Consideration was also given to phenomenological and scientific studies on the mechanisms and causes of evolution, with the evolution of the past being used to inform simulations of possible future evolution of the sites. The bio-geoprospective study provided prognostics on the regional and local evolution of the climate, geomorphology, soils and vegetation that could be present at different times. This was used to develop ecosystem descriptions for each climate and biosphere type.

Climate evolution was a deciding factor for the definition of biosphere types and a natural evolution for climate was considered with both moderately disturbed and highly disturbed evolution alternative scenarios also being applied. The results of the climate simulations provided a succession of climate states over time and the plausible dates at which they could reasonably be assumed to occur. Under a natural climate evolution scenario, temperate conditions could be present at any time, but boreal and tundra type biospheres were plausible after 50,000 and 100,000 years, respectively. For the highly disturbed climate scenario, temperate climate conditions could again occur at any time, but warmer sub-tropical climate conditions could occur in the first few thousands of years and cold periods would be delayed until around 200,000 years and the initiation of boreal conditions. Three plausible biosphere types were therefore identified for a natural climate evolution scenario (temperate, boreal and tundra), whereas for a highly perturbed climate scenario, two additional biosphere types were identified – sub-tropical with winter rain, and sub-tropical humid. For each plausible climate-biosphere situation, a conceptual model is developed, with each being considered equi-probable.

For the CSA facility, which is a near-surface disposal facility, shorter timestep simulations of climate were required. Use of 100-year timesteps rather than the 1000 year steps used for Cigéo identified that a warmer biosphere would be plausible within the assessment timeframe to be considered. Both temperate and warmer climate biospheres therefore need to be considered for the near-surface facility.

A near-surface aquifer is located close to the disposal site. Under natural climate evolution scenarios there is little difference observed in terms of discharge locations. However, under disturbed climate scenarios, different discharge areas may occur. A warmer, wetter climate has the largest effect on the system.

2.4 ROLE OF FEP LISTS AND FEP SCREENING

Mike Thorne (BIOPROTA TST) presented briefly on the role of FEP lists and FEP screening in the BIOMASS methodology. FEP lists sit at the side of the BIOMASS methodology and supports several stages. The list of FEPs is included in Appendix B4, but it is not structured according to the different contexts and purposes where the FEPs are used and it is suggested that a more structured approach may be taken in any update. The existing BIOMASS FEP list is essentially a ‘shopping list’.

Previously, Nirex developed a directed diagram from a top-down approach, to consider what would be needed to calculate human exposure. The diagram included ‘wormholes’ to link to other, more detailed, diagrams (Figure 2-1). The need for multiple wormholes to link to more detailed diagrams was considered messy. Logically there is a lot to be said for a top-down approach in this context, but stopping rules are necessary and there is a need to ensure uniform consideration of all pathways, since experts will have different views on the levels of detail that need to be represented.

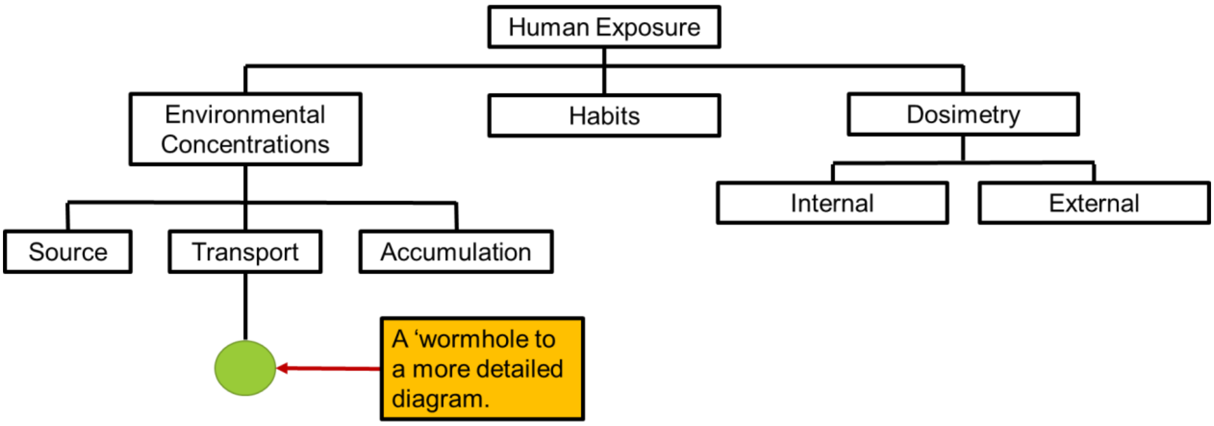

Figure 2-1. The Nirex top-down approach to considering human exposure assessment requirements.

Since the publication of the BIOMASS methodology, interaction matrices have become more commonly applied in assessments. They are considered useful in thinking of the different system components and the processes that link them. They present an element of comprehensiveness and auditing that isn’t present in FEP lists, but thought can be given to whether FEPs can map into an interaction matrix, such that they are used in a complimentary manner.

As repository programmes develop from generic to site-specific phases, the use of FEP lists changes, as illustrated in Figure 2-2.

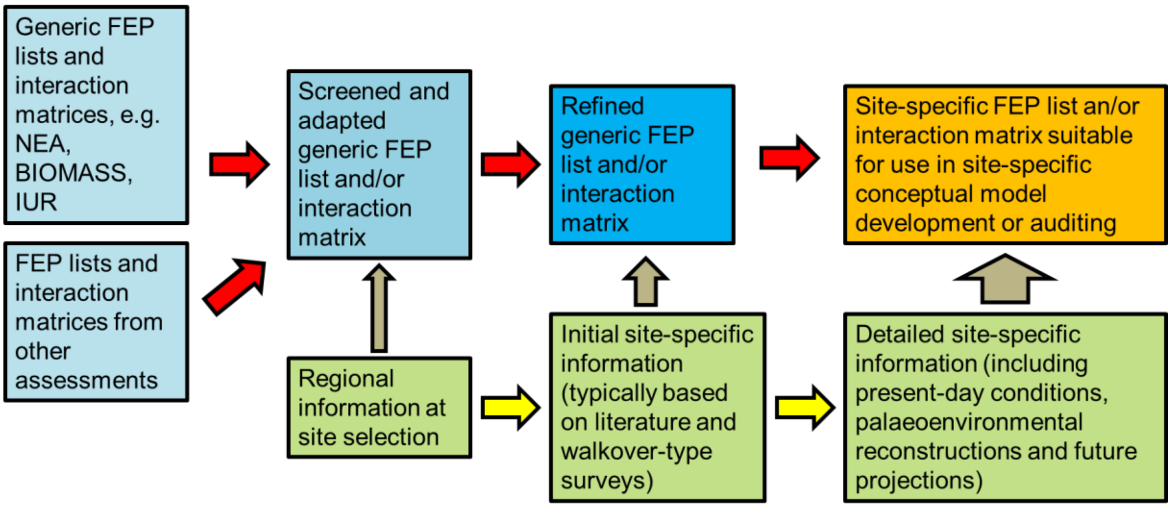

Figure 2-2. Moving from generic to site-specific FEPs.

FEPs on a specific topic should be comprehensive but not overly detailed, with the span of issues being covered, ideally, without overlap and certainly without gaps. FEP analysis is intended to be comprehensive, but this may result in an extensive hierarchy at generic stages, much of which will be irrelevant in a site-specific context. In site-specific assessments, there is little evidence that a FEP analysis identifies considerations that are not already identified by other techniques, e.g. development of a site-descriptive model, and experience suggests that interaction matrices are much more useful because they place understanding in a context and can be more readily related to conceptual model development. It should be recognised that the development of FEP lists and interaction matrices should be considered as living processes within assessments, such that they are revisited and refined throughout the different programme stages, as site understanding increases, to help ensure that they provide a defined basis for site-specific conceptual models.

The usefulness of FEP lists changes in moving from generic to site-specific stages, but they can still be useful during later stages as a check that no important aspects have been unintentionally omitted. In earlier generic stages of assessments, the FEP lists are used in screening to give confidence as a 'sanity check'. The FEP lists may also help in regulatory review of models. It was therefore considered that FEP lists should continue to be covered in the enhanced methodology, but emphasis should be on the development of site understanding as a key focus area in assessments. Consideration could be given as to whether FEPs could be grouped according to programme stages and examples could be provided to illustrate their application. The FEP lists are currently structured as the FEP name and a short description of that FEP. However, in assessments, the properties of the system that can influence FEPs are also considered and it may therefore be useful to also associate defined properties with the FEPs that would aid in the development of interaction matrices, providing information on what influences a FEP and what they are influenced by.

2.5 BIOMASS ENHANCEMENT: ENVIRONMENTAL PROTECTION

Karen Smith (BIOPROTA TST) summarised work undertaken to date on enhancement of the methodology to account for environmental protection.

Non-human biota (NHB) was recognised as a potentially important endpoint for assessments within BIOMASS, but no guidance on evaluating impacts was available at that time. Since its publication, however, there has been a lot of development internationally, including explicit protection requirements, assessment frameworks (e.g. ICRP reference animals and plants, RAPs) and assessment tools (e.g. ERICA). There are also some assessment criteria, although none are as yet internationally agreed. Furthermore, a lot of experience has been gained on the application of these methods within assessments. A task was therefore set during the October/November project meeting for the BIOPROTA TST to consider how to explicitly incorporate NHB as an assessment endpoint within the enhanced BIOMASS methodology.

The original BIOMASS methodology document has been reviewed and areas identified for highlight/inclusion of environmental protection. In many instances, inclusion can be achieved by modifying terminology. However, some areas and some topics may require further explicit thought, such as some climate conditions where biota may be most exposed or where alternative habit assumptions would be required. Aspects where a different approach may be needed to integrate biota protection rather than being treated as an after-thought have also been identified. For example, maximising assumptions for human exposure may not be the most appropriate in evaluating the potential exposure of NHB and alternative scenarios may be more appropriate.

A new method section is suggested, either stand-alone after the potentially exposed group step, or a sub-section within that. This should include principles for how to define assessment species.

Particular aspects that could be considered in the enhanced methodology include the following.

- Why look at population-level protection?
- Tiered approach from generic to site-specific, whereby
  - Site-generic – maybe use RAPs etc., recognise spatial scales relevant to populations; we have illustrations from RWM and NWMO that provide nice examples of site-generic biota assessments, but in different levels of detail.
  - Later phases to site specific – move from reference species to representative species based on site characterisation etc.; we have examples from SKB and Posiva.
- Provision of guidance on the selection of assessment species (e.g. use of food webs to ensure inclusion of all functional groups, stakeholder expectations, exposure pathways etc.).
- Provision of guidance on how to make assessment tools do what is needed (e.g. integrating ERICA into assessments to allow time-dependence to be easily assessed).

Within the assessment context, consideration of biota as an endpoint would also trigger some additional enhancements, such as with regard to regulations.

Some top-level questions need to be considered that will shape any enhancements relating to NHB, including terminology, what level of understanding we assume in providing guidance and which examples to use.

- With regards to terminology, there are a lot of different words that are used: NHB/biota/wildlife/flora and fauna. We need to decide what we prefer and stay with it. For humans, we use Potentially Exposed Groups, do we want similar for biota, e.g. Potentially Exposed Populations (PEP's)?
- In terms of level of knowledge, should we assume that people generally know how to do the assessment, or provide more prescription?

- Protection criteria – should guidance mention the values that are there? For example, ICRP 124 on DCRLs suggest that the lower band of DCRL is the compliance criterion.

It is becoming an increasing requirement for explicit demonstration of NHB protection in assessments, but assessments should be optimised in terms of effort required to demonstrate protection whilst meeting regulatory requirements and expectations. Environmental protection in the methodology should be fully integrated and incorporated throughout, including highlighting implications for site investigation. In terms of guidance on assessments, it was agreed it would be appropriate to reference out to methods (e.g. ERICA, RESRAD-biota) rather than providing full explanations of tools etc. within the enhanced methodology. Assessors would then decide on the most appropriate approach and tools to fit with their assessment context.

In terms of protection endpoints, populations are commonly agreed to be the focus for NHB, but information is required on how populations relate to environmental protection, there is some concern that focussing solely on population protection may be too restrictive. Discussion will be required in the enhanced methodology. It may be appropriate in taking this topic forward to discuss with WG5 of the MODARIA II programme, which focuses on biota dose assessment. The measures put forward with regard to environmental protection within the enhanced methodology should be commensurate with risks to NHB and ideally a simple, proportionate approach should be described.

2.6 MODELLING RELEASES TO ESTUARINE, COASTAL AND MARINE ENVIRONMENTS

Russell Walke presented a site generic example of modelling estuarine, coastal and marine releases from a geological repository from work done on behalf of RWM. Given the site-generic status in the UK, the model does not represent environmental change so provides a ‘snapshot’ assessment approach. The focus of the model is on a present-day climate and potential doses to people; concentrations in environmental media can be extracted for input to NHB assessments. Model development followed a BIOMASS-type approach, but without full FEP analysis. System conceptualisations are illustrated in Figure 2-3.

By considering the different estuarine, coastal and marine systems, different zones could be conceptualised that informed the model discretisation into compartments. The model includes the potential for interaction between the systems, e.g. with discharge from the estuary and coastal components exchanging with the local marine area and feedback from the local marine model to allow for sea-to-land transfer. Development of an overall conceptual understanding of the system was supported through interaction matrices. These conceptual matrices were then screened to identify those processes that needed to be explicitly included in the mathematical models. Parameters were selected to be consistent with those used in the generic terrestrial assessment model and were based on general UK data, drawing from a range of sources, including operational discharge dispersion model assessments and data applied in the LLWR 2011 Environmental Safety Case (ESC).

Different human behaviours were considered to identify exposure pathways and whether the exposure pathways were motivated by occupational or recreational activities. UK habit surveys were used in defining exposure groups and both typical and high ingestion rates were considered.

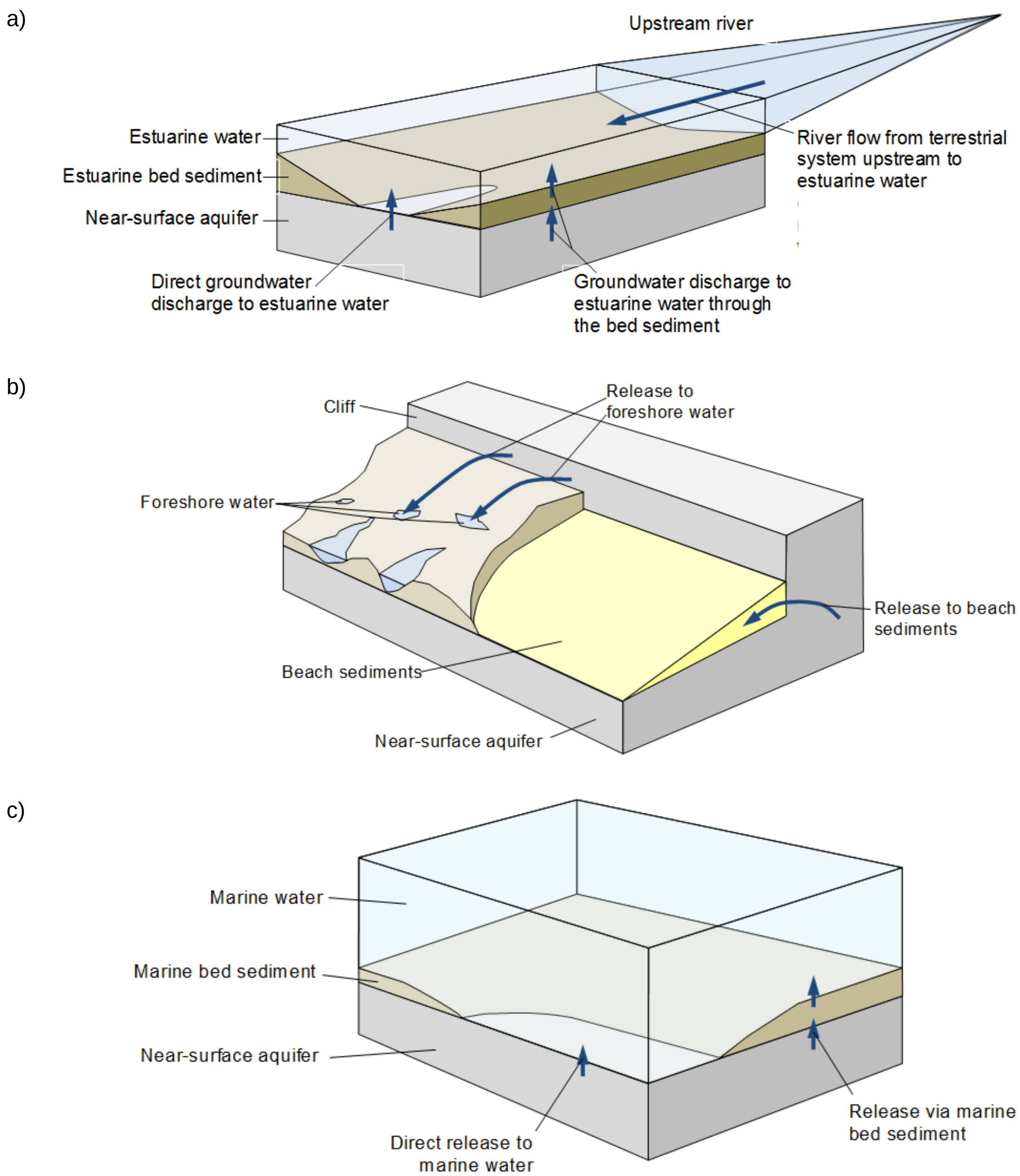

Figure 2-3. Conceptualisations for UK generic estuaries (a), coastlines (b) and marine systems (c).

The sensitivity of the model has been tested for a range of physical characteristics and various other parameters with sensitivity being investigated individually and in combination. For a large number of variants, there was little difference observed, but for some the effects were notable. For example, the size of an estuary had a large influence on dose due to the difference in available dilution and maximising sorption in an estuarine case was found to hold radionuclides closer to the point of release. Changes in the sediment load and sorption had different, and sometimes non-monotonic, effects depending on the radionuclide. Overall, however, dose factors from estuarine, coastal and marine pathways were a small fraction of those resulting from a terrestrial release.

2.7 INTERACTION WITH THE GEOSPHERE (INCLUDING DISCHARGE AREAS)

2.7.1 What is a site?

Ulrik Kautsky presented some learning points from experience from SKB's site characterisation programmes.

In the early stages of SKB's programme for disposal of radioactive waste in Sweden, hypothetical sites were used that were based on real sites to support model conceptualisation. Two sites were later selected for more detailed investigation (Forsmark and Laxemar). At the Forsmark site, there is a geological lens present. If geologists were responsible for developing a site characterisation programme then the focus of the programme would be on this lens, but that would miss the discharge areas that were likely to occur elsewhere and it is these discharge areas that should be an important focus for biosphere characterisation studies.

With the potential disposal sites both being coastal, discharges to the marine environment were likely and yet early characterisation programmes focussed on the terrestrial system and marine deposits were not included, since the focus was very much on the area associated with construction. Arguments had to be made for the inclusion of marine deposit characterisation studies. There is also a need to consider whether analogue sites will be required to derive data in support of alternative climate conditions and the processes at work in those climates.

There is a tendency to define biosphere areas in terms of rectangles. However, a much more realistic and appropriate way would be to define the biosphere in terms of catchments. There has also commonly been a separation between the biosphere and geosphere, but such a differentiation is not considered useful, since it is ultimately all one system consisting of a local biosphere, which is the surface ecosystem, and external conditions (the rest of the biosphere). In this regard, interaction matrices were not found useful by SKB, since the matrix pushed toward geosphere and biosphere separation to avoid becoming unwieldy. There is also a tendency to delineate the biosphere into objects where the main fluxes of radionuclides can be envisaged, but the actual area over which fluxes occur may be much larger, so there can be risks with focussing on too small an area; multiple discharge areas could occur.

There is a need to define the biosphere that is to be studied and a uniform approach and use of terminology is important since different interpretations can be used for the same word by different disciplines. For example, sediment had different meanings for geologists and biologists and after much discussion, SKB decided on the term 'regolith' in place of sediment.

Even when a site has been selected it is not clear what that site is. For example, it is important to recognise that the discharge locations are not necessarily in the immediate vicinity of the disposal site itself and discharge locations can be affected by factors such as climate, hence analogue site information can be important in supporting understanding of the influences on a system. The complexity of a site also increases with site characterisation as more becomes known of the different elements and their interplay.

The biosphere assessment group at SKB had an important role to play in ensuring site characterisation activities encompassed all aspects of potential importance, rather than focussing too narrowly on the immediate vicinity around a site. Engagement of the biosphere team in the early planning of a repository is therefore very important.

Experience has shown that, whilst separation of the near field, geosphere and biosphere sometimes needs to occur, this is not helpful during the planning stages of repository programmes. Releases to the biosphere are often provided at the late stages of assessment without recognition of the assessment work required in evaluating potential impacts form those releases. Engagement of all assessment groups is therefore vital within a total system assessment to ensure that the assessment processes are understood and appropriate information is shared within appropriate timescales.

The biosphere is sometimes considered as a measuring tool, since it does not provide a particular safety function. However, some biospheres can be worse in terms of releases and consequences than others. Therefore, whilst the biosphere does not form part of the engineered system and there are no controls that can be placed on the biosphere, it does form part of the overall system and can help inform on siting to improve overall safety. The importance of the biosphere is further increased when moving from deep geological disposal facilities to near-surface or surface facilities.

2.7.2 Water transport through soil layers

Emma Johansson presented a case study of numerical modelling of particle flow paths from the interface between the bedrock and regolith to the surface at Laxemar, Sweden. The case study was part of a safety evaluation for a potential repository for low-level, long-lived radioactive waste, termed SFL.

A surface hydrology model has been developed. The Laxemar landscape is hilly, with a gradient toward the sea. Small lakes and wetlands are present. Compared with the deep bedrock, the upper bedrock has a higher fracture frequency. The surface hydrology model overlaps with the deep hydrogeological model to allow a continuous story of hydrological flow through the bedrock.

Lakes have been conceptualised as having sediment layers above the bedrock that can develop into wetlands and agricultural land systems over time. Particle positions, having been traced through the bedrock using the hydrogeological model, are used as input to the surface hydrology model, with input being to the uppermost bedrock. The calculated exit points are concentrated on two biosphere objects and local hydrology models have been developed around these objects. Each sediment layer is considered in its own right, with particle flow path length and travel time being analysed for each. No sorption or chemical processes were assumed, as it is water transport that is being evaluated.

72% of particles were lost from the saturated zone to the river system. The majority of particles left the soil layers after two years, with particles having flow path lengths of between 20 and 50 metres through the soil. The porosity of the soil is to be further considered as the travel time was considered too short, although soil layers are very thin at the Laxemar site.

The slowest travel time was associated with a clay layer, whilst the longest flow path length was in a sand layer. Vertical transport dominates in bedrock, as well as in the clay layer. However, on reaching the sand layer, horizontal transport dominates. Clay therefore dominates vertical transport and sand dominates horizontal transport.

The water fluxes between each soil layer for the whole biosphere object have been extracted to inform the dose model. However, only part of the object is associated with active transport of particles. The horizontal fluxes include inflow from other objects. Further work is required on the hydrological properties of the site. It is likely that a similar study will be undertaken for Forsmark, where more is known about the hydrology of the system. The model can be adapted to account for site-specific geological layering. The horizontal resolution of the model cannot be varied, but the vertical resolution can and different hydrological properties of each layer can be altered such as the hydraulic conductivity of different media.

The study focussed on the transport of water, but a parallel study is underway to look at the transport of elements and results will be compared with that from the previous model. The model will be reported in SFL safety documentation.

2.7.3 Considerations for the revision of the BIOMASS methodology – a regulatory perspective

Shulan Xu presented some suggestions for the revision of the BIOMASS methodology, based on experience in the regulatory review of license submissions. The focus was on the identification of biosphere objects and their modelling. A document on the review of regulatory guidance and dose constraints for longer-term release is due to be published in 2017.

Over several decades, biosphere modelling has been developed through various programmes, including BIOMOVS II, BIOMASS, BIOCLIM, EMRAS and MODARIA.

Three different conceptual flow models can be considered in terms of the migration of radionuclides through the geosphere to the biosphere – a channel network, discrete fracture or stochastic continuum. From the several decades of biosphere modelling performed by SKB for various disposal programmes, it has been shown that discharge points are always concentrated to the lowest points in the landscape such as lakes, rivers or wetlands, with clusters of discharge points being used to identify the location of 'biosphere objects'. Biosphere objects are therefore delineated around discharge points. This approach allows a natural determination of the size of the biosphere object to which release occurs. A conservative assumption of all releases then going to one object can be made. However, it is then assumed that the release is instantaneously mixed throughout the entirety of the biosphere object, which may not be a conservative assumption and further work is therefore needed to look at the uncertainty around adopting this assumption rather than considering a more focussed release within the object. However, if the size of the biosphere object or release area is too small then the area would not be capable of sustaining people and this should be recognised.

Surface hydrology can be modelled for biosphere objects subject to long-term climate change using very detailed models that provide a full description of the landscape with biosphere object evolution. Alternatively, simple assumptions on the hydrology of each object could be applied with a statistical approach used to represent the spatial and temporal variation. Irrespective of the approach taken, it is important to apply a consistent approach to how transport is modelled throughout the surface system and to consider the appropriate scale of the sub-catchment area used in the delineation of biosphere objects.

Points to consider in the update of the methodology identified during discussions include the following.

- The integration of site descriptive information within model development should be incorporated in the methodology, with examples provided.
- It is recommended that biosphere objects be considered in their entirety, both large and small, with some statistics applied to account for doses incurred from multiple objects rather than bulking all objects together.
- With landscape evolution, it is possible that release locations will progress from lakes to wetlands and ultimately to terrestrial landscape releases as shallow lakes infill. Succession that is observed today can be used as a tool to construct process models to represent future landscape evolution.
- It may be appropriate to consider whether there is an alternative and better term than 'biosphere object'. The size of objects can be influenced by human habits and endpoint assumptions and,

whilst hotspots may occur, it is necessary to recognise that certain areas are required to sustain people and populations. It is also important to recognise that the upstream catchment is a component that cannot be neglected and it may be appropriate to consider an object within an overall catchment area to support delineation.

2.7.4 STUK release constraint limits

Ryk Klos presented information from a review of regulatory guidance and dose constraints for longer term release that is due to be published in 2017.

Release constraints are used in Finland that relate to the activity that may migrate to the living environment after several thousand years at the earliest. The release constraints are set by STUK using simple models and are set so that assessors only need consider flux for longer-term releases from repositories. The constraints draw on site descriptions from Posiva. Interaction matrices have been found to be useful in developing conceptual models.

Site descriptive models are not the same as landscape models, the landscape models are an abstraction. The models can be used to illustrate the role of release locations and analyse catchment areas. The release locations will vary depending on the failed disposal canister. The Posiva approach has, therefore, been to consider all potential locations and to identify the worst case in terms of contaminant release to the surface environment. Catchment areas can be very useful in considering the flow of water through the system and dilution. Small catchments will result in higher doses due to lower dilution. It is important when undertaking assessments not to pre-judge the worst-case release scenario. For example, the use of wells for extraction of groundwater is often considered a worst case for human exposure. However, peat bogs have been demonstrated to result in higher potential exposures for some assessments through the accumulation of radionuclides in the peat bogs and their subsequent agricultural use[f].

The complexity of assessment models has increased significantly over time with a move from simple robust models to more detailed site-specific models to account for systems that evolve over time. Following the regulatory review of modelling undertaken by Posiva, it has been concluded that the landscape modelling is both extensive and detailed. However, the usefulness of detailed models reduces over assessment timescales as uncertainties increase. Beyond 10,000 years therefore the focus is on the use of release constraint limits and the quantities of radionuclides that are released from the bedrock. The bedrock is close to the surface and the bedrock-to-overburden transition is the geosphere-biosphere interface. Dynamic models are required to account for accumulation in the surface overburden.

The release constraint limits have been recalculated to account for the new information available from Posiva's studies. The new constraint limits are one order of magnitude, or more, lower than the generic constraint limits that were calculated in 2002. The reduction in the constraint limits is, in part, due to a wider set of biosphere objects being considered that are linked to likely release locations,which results in constraints that are local to the site. The work on revising the constraint limits has demonstrated the importance of using site data to ensure that local conditions are taken into account.

The work undertaken followed the key steps of the BIOMASS methodology and provides information and examples around iteration between modelling stages and the integration of detailed site-specific

[f] Other cases were presented in the original BIOMASS methodology report.

information in informing system identification and justification for specified biosphere objects and on model identification and justification.

2.8 EXPOSURE DEFINITION

2.8.1 Clarifications for the identification and description of potentially exposed groups

Lise Griffault presented a series of questions and suggestions around enhancements of guidance on the identification and description of potentially exposed groups, following-on from experience in applying the BIOMASS methodology within safety cases. Overall, it is considered that clarification is required on the justification and description of potential exposures within the BIOMASS methodology. The key questions, observations and suggestions are outlined below.

- The definition of the biosphere requires clarification; does the biosphere relate to the easily accessible environment, or the global sum of all living beings and the environments they live in?

- The use of different terms and their definitions within the updated methodology needs to be carefully considered. For example, critical group, representative individuals and potentially exposed groups have all be used and the current recommendations on terminology should be applied.

- There is a need to update the methodology to include assessments for hazardous chemicals, and also for non-human biota as a specific assessment endpoint.

- The identification and description of exposure groups depends on multiple factors, including location, outlets, activities, food habits and climate, all of which are interlinked. A first step in assessments is to identify the climatic conditions and their evolution, including anthropogenic effects. This involves considering the type of biosphere and features such as rainfall and temperature. Whether probability should be taken into account when considering biospheres should be discussed. The identification of the release point and the type of release (water or other) is then a second step. It is not just water release that should be considered, diffusion through soils could also result in release and the type of facility will influence the type of release. Discussion around what an outlet is would therefore be beneficial, taking account of both natural outlets and human activities and the different types of disposal facilities. This would be particularly relevant for scenarios around borehole pumping, with some organisations considering this as a normal evolution scenario and others considering in terms of human intrusion scenarios. The way in which cases are assessed will vary depending upon whether a scenario is considered as normal evolution or an unusual event.

- Once outlets have been identified, the next step is to define human activities and potentially exposed groups by linking outlets to possible human activities. There were a number of difficulties encountered when considering all exposure pathways. For example, an outlet may vary through time and space and usage may also be variable. How water resources compatible with human requirements should be defined needs greater consideration, along with the degree of realism that should be integrated in assessments in terms of productivity of outlets and whether low-productivity outlets can be excluded. The influence of outlets on each other also needs consideration. For example, how water extraction from a well could affect river flows where both draw on the same aquifer and how compatible flow rates could be defined.

- Human activities can be identified through *a priori* or *a posteriori* approaches. In the early stages of a programme, the *a priori* approach may be appropriate to explore all potential transfer pathways by considering either multiple exposures in relation to multiple activities or by considering a specific exposure pathway in relation to a specific activity. The *a posteriori* approach may then be more appropriate when the project is well advanced and the most exposed group or activity known. If this approach is agreed, then it should be explained and iteration emphasised.

- In terms of the representative individual, consideration needs to be given as to how to conform to ICRP requirements. In some assessments, only the adult is considered, whereas in others, both infants and children are also evaluated. Consideration is needed as to what should be suggested in BIOMASS. Furthermore, some discussion would be useful around whether the same representative individual should be continued through the operational and post-closure assessment stages or whether different assumptions would be appropriate.

- The degree of autarky (self-sufficiency) that should be assumed in assessments is a further area that needs to be discussed. During the operational phase, Andra considers consumption rates derived from local surveys, but for the longer term it is not known what people will eat or how they will obtain food. Discussion with others on approaches, including assumptions around different exposure pathways, would be beneficial to providing suggestions in BIOMASS, such as avoiding extreme behaviours in assessments.

- For human behaviours in the long-term, there will be considerable uncertainties (for example, whether rivers will be present in the future etc.). How such uncertainties should be taken into account could be discussed.

- In summary, the following clarification areas were identified in relation to exposure groups:

    - Principles for defining representative humans and populations of wildlife.

    - The need to consider climatic evolution.

    - The need to characterise and choose the outlets as a first step before the identification and selection of potentially exposed group(s), including:

        - the need to discuss diffusion in soil from subsurface disposal;

        - what is a natural outlet versus human activities (wells, boreholes); and

        - important parameters such as aquifer productivity and dilution.

    - The need to define what is a resource compatible with requirements, including whether there is there a limit (i.e. should a group be defined when productivity is low and should the quality of the water be accounted for?).

    - How to select human activities and consumption rates.

2.8.2 ICRP and other consideration of representative persons

Graham Smith (BIOPROTA TST) provided an overview of ICRP requirements in terms of representative persons. For waste disposal and long-term assessments, representative persons or critical groups are hypothetical. Overly cautious assumptions should be avoided, but clear guidance, with examples, on how to achieve this is lacking. There will always be some individuals with extreme behaviours; however, the selection of behaviours leading to assessed doses for comparison with ICRP recommendations on constraints relevant to waste disposal should be below these extremes.

The terminology connected with representative persons and members of critical groups used by the ICRP has changed over time, but there does not appear to have been much effect on the way in which assessments are undertaken or how regulations are applied. However, use of ‘representative persons’ as suggested in ICRP 101 could result in too much focus on the dose to the most exposed person rather than a group. ICRP 122 then introduced the concept of risk-informed decisions for geological disposal, suggesting it may be appropriate to consider both the size of the dose and the probability of occurrence. Whilst there is an apparent contradiction in guidance from ICRP 101 and 122 as to whether adults only or adults, children and infants be assessed, ICRP Publications 81 and 122 are very clear that for the continuing exposures (lasting a lifetime), as might occur following releases from radioactive waste repositories, it is not necessary to consider children and infants in post-closure waste disposal assessments.

The BIOMASS data protocol approach appears to have been over-interpreted in many assessments to mean use ICRP default dose coefficients without taking into account the environmental conditions under which exposure is assessed to occur.. This should be clarified to ensure that guidance is not prescriptively interpreted. This can take account of recent publications in the Journal of Radiological Protection concerning selection of relevant dose coefficients[g], while recognising the uncertainties in the models used to calculate dose coefficients[h]. . Further guidance, in line with ICRP recommendations, could also be given suggesting that it should be clear whether dose assessments are intended to be cautious (e.g. for comparison of individual doses with dose constraints) or realistic (for use in optimisation and determining the selection between options).

In Finland, in addition to a dose constraint for the most exposed people, there is also a requirement to evaluate dose to other people in the population, which reflects previous ICRP and other recommendations to consider the number of exposed people as well as the magnitude of individual doses. The approach also helps avoid incidental over-dilution of peak doses within a larger distribution since the dose distribution across the more exposed populations has to be addressed. Consideration therefore could be given as to whether presenting distributions of dose could be helpful, particularly in terms of communication.

2.8.3 Land-use and food intake of future inhabitants

Peter Saetre provided an overview of the SKB approach to defining a representative individual of the most exposed group. Defining the most exposed group requires a philosophical basis and reasonableness, and the SKB approach has been to keep things simple and reasonable with an iterative process undertaken with regulatory consultation to agree on the approach.

The regulatory criteria include a factor that can be taken into account if the exposure group is very small such that a higher safety criterion can be applied. The approach taken to assessing dose has been based around carbon intakes with all radionuclide intake being scaled in terms of carbon. The starting point was ICRP Reference Man with energy demand being translated into carbon demand.

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[g] Harrison J D and Leggett R W (2016). Appropriate selection of dose coefficients in radiological assessments: C-14 and Cl-36: response to the letter of G Smith and M Thorne (2015 J. Radiol. Prot. 35 737–40). J. Radiol. Prot. 36 (2016) 388–390

[h] For example: Puncher M, Zhang W, Harrison J D and Wakeford R (2017). Assessing the reliability of dose coefficients for exposure to radioiodine by members of the public, accounting for dosimetric and risk model uncertainties. J. Radiol. Prot. 37 (2017) 506–526 (21pp)

To identify the most exposed group, the biosphere must be known so that exposure pathways can be identified. A detailed analysis of exposure routes has been undertaken for releases to various biotopes as a starting position and around half of the initial exposure routes later screened out, based on unit release analysis. Land-use scenarios and potential exposure groups are described in AMBIO 2013, 42: 448-496. The communities for which exposure would be maximised were identified (with ingestion being the dominant exposure mode) and a reasonable fraction of diet items selected. Constraints on land use were taken into account, such as physical size and productivity and human requirements. Land-use characteristics were drawn from historic self-sustained communities with a hunter-gatherer lifestyle being used as an upper bound based on maximum use of resources from the environment. The site then needed to be considered to calculate the fractions of diet in a changing landscape. The home ranges of exposure groups needed to be taken into account, with biosphere objects potentially being smaller than home range requirements.

Communication should be considered throughout the process of identifying exposure groups to help ensure that the groups are reasonable and justifiable. Historical agricultural practice in Sweden was researched to consider what could be farmed and the area that would be required for production. The level of technology assumed was consistent with being able to drain a mire.

The overall approach was therefore to tell a reasonable story, based on history and landscape resources rather than using a 95%-confidence approach to selecting habits. The exposure groups were used as credible analogues that provided bounding cases. A minimum area of 6 ha was identified, which has the potential to support two families.

Where a carbon-based approach to habits is adopted, consideration should to be given as to how this should be communicated in terms of how carbon intake relates to food. Whilst the carbon approach is common in ecology, it can be difficult for members of the public to understand. The SKB approach was not to explore the influence of diet on the dose, but rather to calculate the dose from relevant exposure pathways resulting from living in, and making use of natural resources from, the area with the highest concentrations of radionuclides. Care should be taken in assuming that total autarky is a worst exposure case if the release area is smaller than the area needed to support the most exposed group. Animals require a large area and therefore, if animal production is excluded, the area required for crop production will be lower and exposure may be increased.

2.8.4 Application of the BIOMASS methodology by Andra for identification and description of hypothetical reference groups

Lise Griffault presented the approach taken by Andra to identify and describe hypothetical reference groups. The safety guidelines require that hypothetical reference group(s) are defined on the basis of observations of biosphere(s) representative of the typical biosphere to be modelled over an assessment timeframe of 1 million years for a deep geological repository.

There is a river in the vicinity of the disposal site, but this was not selected as the outlet point since a river would give greater dilution than direct use of the aquifer. Furthermore, the aquifer is of low productivity so multiple outlets were rejected. Direct use of the aquifer was therefore selected, in agreement with the objective of maintaining realism. The productivity of the aquifer was also used in evaluating food production.

The long-term evolution of the site was taken into account and whether this could result in a new outlet over time or the outlet moving to a different location. An *a priori* approach to identifying habits was applied in a systematic approach to ensure that key aspects were not omitted. The BIOMASS table on foods and activities for different exposure groups was used as a reference for different exposure groups.

For a representative person, it is important to keep in mind the habits of stakeholders and include these within the assessments. Diets of particular groups were checked to ensure specific activities were captured and local food habit surveys were undertaken in collaboration with IRSN. For the operational and surveillance phases, habits were assumed to remain consistent with the local habit surveys. For the post-closure phase, a certain continuity was maintained, but a greater focus was placed on full autarky. For any pathways and habits that were not included, their exclusion was fully justified. For each exposure group, a representative individual was described according to age class, exposure pathways and dietary habits. All potential transfer pathways were explored by either considering multiple exposures, based on average behaviours, or by considering a specific exposure pathway for which extreme (95^{th} percentile) habits for the pathway of interest were assumed (e.g. high cow meat, milk and cheese consumption by cattle farmers), with all other intakes remaining at average rates.

The exposure groups relating to different climate cases and typical biospheres representative of those possible climate states were considered. Conceptual models were developed for each selected typical biosphere. When the highest exposure pathways are identified there will be *a posteriori* iteration to reduce the number of exposure groups and habits to focus on the key activities in the assessments.

2.9 GUIDANCE FOR ASSESSMENTS ON SHORTER TIMESCALES

Mike Thorne (BIOPROTA TST) presented.

The BIOMASS methodology focussed on long-term post-closure assessments for geological disposal facilities. However, there may be a need to consider shorter timescales in assessments. This may be the case for facilities that are nearer to the surface environment (e.g. disposal of LLW or short-lived ILW) or as a first, detailed stage of a longer-term assessment (e.g. in moving from the operational to post-closure phase) or for facilities that have a limited lifetime as a result of natural processes such as coastal erosion. There may also be a regulatory requirement to undertake specific and more detailed quantitative assessments over the first few thousand years.

Unlike assessments over very long timeframes, the first thousand years can be visualised in human terms, in that there is recorded history of a similar timescale, existing buildings and relict landscapes and people have interest in their families into the future and the environment in which they will live). There is therefore a public perception issue. It may therefore be reasonable to tell a continuous story from the present day to the end of the assessment period, from the operational stage, through the monitoring phase and the post-closure phase and consider the evolution of the system throughout. This includes consistency in assessment assumptions, with only clearly justifiable changes, e.g. in exposure group behaviour. Such an approach may help focus attention on site controls and consistent assumptions on controls and climate projections etc. throughout the assessment timeframe and between different assessment communities.

There has been a lot of learning on the extraction of knowledge from long-term modelling and use of site characterisation data to inform on operational phase modelling that could be drawn upon to provide useful suggestions within the revised methodology.

2.10 CONFIDENCE BUILDING

2.10.1 BIOMASS update: confidence building

Russell Walke (BIOPROTA TST) presented.

Assessments are used to support decisions; sufficient confidence is needed in assessment results to support those decisions. There are significant uncertainties associated with long-term assessments, not least of which is an inability to predict the future. Furthermore, different people require different levels of information to gain confidence. Assessments seek to provide a reasonable level of assurance, as absolute assurance is impracticable given the uncertainties. Aspects that can add to confidence in assessments include use of a systematic scientific approach, ensuring assessments are logical, transparent and robust with both simplifications and complexities being justified. Assessments should also draw on widely used practice and international experience. Quality assurance and verification are also essential in demonstrating that mistakes have not been made.

There are three broad types of uncertainty – scenario uncertainty, model uncertainty and parameter uncertainty. Scenario uncertainty is the key in helping to ensure that nothing has been overlooked, with scenarios being important in terms of stakeholders. Model uncertainties can be addressed through side calculations, validations and inter-comparisons. Multiple approaches can also be employed. For parameter uncertainties, there are various approaches to improving confidence, including use of multiple bounding cases and probabilistic sensitivity and uncertainty analyses.

FEP lists can be a useful tool in providing confidence that important aspects have not been overlooked and interaction matrices can be used to support system description and conceptualisation. The use of analogue sites and information can also be valuable in developing confidence, drawing on information that people can relate to from current situations that represent different climate states.

Stakeholder engagement is very important and engagement at an early stage is recommended, allowing information on how locals use the environment to inform the assessment and giving stakeholders some ownership of the results. A wide range of questions and opinions should be anticipated.

Guidance should show that tools and analogue site information are available to support assessments.

2.10.2 Uncertainty analysis

Rodolfo Avila proposed some revisions to the BIOMASS methodology to update it in terms of uncertainty and sensitivity analyses. Some consideration was given to uncertainty analysis within BIOMASS, but this was limited and enhancements would therefore be advantageous, drawing on experience in undertaking assessments and collaborative work, including the EC PAMINA project[i]. It was proposed that a new section be developed that outlines sources of uncertainty and how to address these. The proposed contents of the chapter are as follows:

1. Sources of Uncertainty

1.1. System Uncertainty

1.2. Model Uncertainty

1.3. Parameter Uncertainty

2. System Uncertainty (quantifying scenario probability when feasible)

3. Model Uncertainty (conceptual, mathematical, numerical)

[i] http://www.ip-pamina.eu/

4. Parameter Uncertainty

    - To include sources (including spatial/temporal aspects), selection of values, probabilistic approach guidance, assigning pdfs, propagation of uncertainties through models and presentation of results and demonstration of compliance.

5. Sensitivity Analysis

    - To include goals, methods and guidelines for sensitivity analysis with illustrative examples.

6. Overall Strength of Knowledge Base

Different concepts around uncertainties and their analysis were presented, along with definitions. It is intended that the chapter would provide approaches to addressing the different types of uncertainty with examples provided. A draft section will be prepared as input to the October/November 2017 Technical Meeting of WG6.

2.10.3 Evaluation of strength of knowledge base

Ari Ikonen introduced the concept of evaluating the strength of knowledge base that supports safety cases. Various methods have been developed to allow the strength of the knowledge base to be assessed, such as Posiva's knowledge quality assessment, which has now been extended to the overall safety case rather than focussing on the biosphere assessment. The approach was also applied to biota dose assessments within a BIOPROTA report[j]. There are various other approaches and applications including in relation to contaminated land management and environmental policy.

A key question to be answered is whether we are confident enough to be able to make decisions. It is not feasible to solve all questions and uncertainties and consideration should therefore be given as to when confidence is sufficient. With the range of different uncertainties, it will be necessary to prioritise and to employ sensitivity analyses on those aspects that matter the most. FEP lists and interaction matrices can be used to demonstrate comprehensiveness and pedigree scoring (see for example Figure 2-4) can then be used to evaluate the level or strength of process understanding of different aspects.

[j] Smith K., Robinson C., Jackson D., de la Cruz I., Zinger I. and Avila R. (2010). Non-human biota dose assessment: sensitivity analysis and knowledge quality assessment. Posiva Working Report 2010-69.

Score	Theoretical quality of model	Empirical quality of model	Social quality, degree of acceptance
4	Established theory, many validation tests, causal mechanisms understood	Experimental data, statistically valid samples, controlled experiments	Total, all but cranks
3	Theoretical model, few validation tests, causal mechanisms hypothesised	Historical/field data, some direct measurements, uncontrolled experiments	High, all but rebels
2	Computational model, engineering approximations, causal mechanism approximated	Calculated data, indirect measurements, handbook estimates	Medium, competing schools
1	Statistical processing, simple correlations, no causal mechanism	Educated guesses, very indirect assumptions, 'rule of thumb' estimates	Low, embryonic field
0	Definitions/assertions	Pure guesses	None

Figure 2-4. Illustration of a pedigree scoring matrix (from Constanza et al. 1992, Environ. Manag. 16: 121-131).

Main assumptions can also be categorised in terms of choices and level of conservatism. An example of an approach is provided in Posiva report 2012-28. Consistency checks can also be made in the choices of data with underlying reasons for data selection being justified and explained so that any revisions in the approach or assumptions in future iterations are transparent. The strength of data basis, using a similar scoring approach to that illustrated in Figure 2-4 can also be evaluated.

Strength of knowledge versus sensitivity plots can be useful in identifying areas where additional effort could be well spent to improve confidence and avoid spending effort on areas that make little difference to the assessment output. Making an overall synthesis of the remaining uncertainties and whether they matter could also be a useful approach to addressing uncertainties and building confidence.

3. FEEDBACK FROM BREAK-OUT DISCUSSION SESSIONS

Three sub-group topics were identified for a break out discussion session focusing on the following enhancement areas:

- potential exposure groups;
- spatial scales in assessments; and
- uncertainties in dose models and confidence building.

Feedback from each sub-group is summarised below.

3.1 POTENTIAL EXPOSURE GROUPS

Terminology was discussed in relation to a variety of different aspects. For example, the definition of the biosphere was discussed. This is often defined as the accessible environment, but this is not considered helpful since humans can access all areas, including the geosphere. Ultimately the biosphere is part of the overall system and is the part of the system where exposure calculations are focussed. This is particularly relevant when considering near-surface facilities that can themselves be located within the biosphere, which is a topic that could be discussed in the enhanced methodology. The IAEA have a 2016 glossary that should be used when deciding on the appropriate terminology, to ensure consistency.

The inclusion of a set of examples of geosphere-biosphere interfaces (e.g. from the BIOPROTA 2014 report on this topic) may be useful and could form an appendix to the methodology. Boreholes are a special case, since they are linked to human intrusion scenarios and further discussion around this may be warranted. It should also be noted that boreholes may not be the worst-case scenario and that explicit examples of this would be useful.

In setting the scene for exposure groups, the role of the biosphere within the overall assessment should be made clear from the beginning, with exposure groups defined in the assessment context as being within the part of the system where radionuclides will end up. The definition of exposure group should also be clear to avoid potential confusion (i.e. it does not mean a family nor a group of people within a specific area – there could be different people receiving similar levels of exposure irrespective of the location). An illustrative example may prove useful in this regard. Furthermore, a questionnaire could be developed to engage with others in the assessment community to draw together information on the exposure groups that are considered, the age groups of people within those groups and whether there are any examples of real exposure conditions where child or infant doses are an order of magnitude, or more, higher than for adults. This information could be used to provide an illustration of the significance of variations in exposures of different age groups for a range of exposure situations.

The implication of the stage of repository development is an important aspect. Assessments may be site-generic, site-specific but without site characterisation, or site-specific with the site having been characterised. Iteration between these different stages should be made clear. The need to engage with stakeholders at an early stage to ensure their interests are addressed should also be made clear.

The BIOMASS methodology should not be prescriptive as to how specific issues should be addressed, but should illustrate how those issues could be addressed. A range of examples of human exposure group definitions relative to regulatory criteria could therefore be provided, along with human-related alternative indicators. Discussion could also be provided around conservative, realistic and likely habits.

The use of aggregated food types in assessments when looking at future human habits may also merit some discussion.

For exposure of people to radioactive and non-radioactive hazardous substances, it should be noted that consistent assumptions should be used wherever possible. Feedback from those having undertaken assessments on what substances have been identified as important would be useful and this could be a topic included in a questionnaire. The questionnaire should be distributed to members of WG6 and the BIOPROTA forum, but also to other relevant people from other countries to gain insight around alternative climates and cultures. A range of key issues was identified that could be covered within a questionnaire, including the following topics.

- Biosphere: what it is, give the definition.
- Role of biosphere in the overall system.
- Regulations relevant to potential exposure groups.
- Are there any examples of real exposure conditions where the child or infant dose is order of magnitude, or more, higher than for adult?
- How are your exposure groups defined, give examples?
- How is the set of food habits defined, give examples?
- What could be clarified in the BIOMASS approach?

The questionnaire could also include questions around regulations requiring biota dose assessment and how assessments are undertaken, including the selection of assessment species.

It was noted that WG4 are looking at models for different climates and there may therefore be merit in engaging with WG4 during the next MODARIA II Technical Meeting.

3.2 SPATIAL ASPECTS OF ASSESSMENTS AND SITE CHARACTERISATION

Issues around spatial averaging and model resolution are recognised as being important. For example, the area of managed systems required to sustain a population will be different from that required from natural systems and the spatial range to be considered in models will also vary with the assessment context, such as a small range when focussing on groundwater abstraction from a well as compared with a large range when full ecosystem modelling and environmental change are considered. The temporal scales of interest may be set by the regulators, but these are still subject to change as regulations are revised. Alternatively, the site itself may inform on the timescales. Each of these aspects feed into what should be studied at a site and how those aspects should be studied. Iteration is recognised as being important.

In updating BIOMASS, a 'laundry list' of what can be done at a site could be developed. This should be kept at a general, but meaningful, level. Guidance from experience at SKB and Posiva could be developed on working from a 'bottom up' approach, whereby models are informed by site understanding, with examples provided. The alternative is a 'top down' approach where site characterisation is led by model needs. The BIOMASS methodology needs to be read by all WG6 and BIOPROTA project participants to identify where updates are needed. It is suggested that the TST then make visible those areas and use flow charts to help manage the process of updating the methodology. The requirement for integration between disciplines is a topic that needs to be incorporated.

Analogue/representative sites can be used to provide stories about alternative climates etc. and guidance could be developed around the use of such sites, informing what they could be used for and how, and the use of data derived from site studies. Studies undertaken by SKB in Greenland could provide a useful example. General information from the work undertaken within WG6 of the MODARIA I programme could be applicable to many assessments, providing information around climate modelling.

It would be useful to catalogue data that are site-dependent and site-independent to help inform what should be considered when designing site characterisation programmes. It should also be made clear that the focus of characterisation programmes should not be too small (i.e. include areas beyond the repository footprint) to avoid potential discharge areas being omitted from study. It is only when potential discharge areas have been identified that characterisation studies can be narrowed to areas of particular interest. Consideration should therefore be given to the appropriate terminology with the term ‘site’ potentially focussing thought on too narrow an area around the repository itself. There is a facility area and then a larger area within which consequences of the facility are investigated. It was therefore suggested that, in place of ‘site characterisation’ the term ‘biosphere characterisation’ may be more appropriate. Revisions to terms would, however, need to be discussed and agreed with the IAEA.

Including some discussion around what is reasonable in terms of identifying and describing biosphere objects may also be beneficial, to include subjects such as what is reasonable in terms of size of biosphere objects. The concept of biosphere objects is just one method of spatially structuring discharge regions. Alternative approaches are possible. How the spatial structure of the biosphere is described will relate to how you characterise the biosphere and build the biosphere model. Where landscape evolution is to be taken into account, a much larger spatial scale is often required, with greater emphasis on aspects of the landscape such as hill slope.

A mind map of the discussion session was produced by Ulrik Kautsky and a pdf of the map plus some discussion around it are to be provided.

3.3 UNCERTAINTY IN DOSE MODELS

The level of detail for the proposed section (or appendix, as appropriate) on uncertainty assessment for the enhanced methodology was discussed. It will be important to ensure that an appropriate level of detail is provided and referencing out to other, more detailed, information sources on different approaches may be a useful approach. Care also needs to be taken not to appear to prescribe either deterministic or probabilistic assessment approaches, as the choice is one for those undertaking assessments and both approaches are often applied.

Advice should be included on how uncertainties can be reduced. This could include topics such as a graded approach to modelling, with conservative models being used to inform on the important aspects and guide further model development. The use of screening versus assessment models should also be made clear and examples of experience could be given. Information on the validation of models and demonstrating that they are fit for purpose could also be incorporated. Error propagation should also be recognised and discussed, as should linking biosphere assessment uncertainty and sensitivity analyses to the rest of the safety case (e.g. the influence of canister failure on discharge location).

Risk dilution is an aspect that could be discussed under this topic. In some assessments, the mean dose is to be evaluated. Uncertainty around risk dilution can be evaluated by testing different assumptions – if doses increase then there was risk dilution. There needs to be caution, however, to avoid over-interpreting assessment results and it should be kept in mind throughout all stages that a proportionate approach should be taken. If overall risk is very low, then there should be limits to the amount of refinement that is undertaken.

A initial draft of the section will be provided to all participants prior to the second MODARIA II Technical Meeting for feedback and further contributions. Examples will be included to illustrate different aspects, but also to illustrate how to interpret the output of uncertainty and sensitivity analyses. It is hoped that experience from different countries can be captured through discussion during the next meeting and through additional examples and comments offered by participants.

4. ACTIONS AND FORWARD PLAN

Potential enhancement areas were summarised, based on discussions during the workshop. Further points to consider when undertaking the next steps were also highlighted. Each is summarised below and any specific actions identified.

- In order to future-proof the enhanced methodology, compliance criteria should be excluded. The process for undertaking an assessment, including how to support assumptions, should be the prime focus.
- A lot has changed in terms of the assessment context since the original methodology was published, including changes to regulatory compliance and endpoints. There have also been considerable advancements in techniques and capabilities in uncertainty analysis and overall radionuclide transport modelling, amongst others. These advances need to be recognised when revising the assessment context, with clear messages given regarding how uncertainty can be managed. Furthermore, confidence building should not be tagged onto the end of the guidance, but emphasised throughout. Links to the total system should also be clear, to help ensure that the biosphere is not considered as an aside to the overall system. All participants are requested to review the assessment context and identify where there have been changes that should be captured for discussion during the next WG Technical Meeting.
- In defining biosphere systems that need to be taken through to assessment, the output from WG6 of the MODARIA I programme will provide an important input. Regional and local climate and landscape evolution is an important factor for defining scenarios for the whole disposal system. The MODARIA I WG6 output should, therefore, not be interweaved within updated BIOMASS methodology, but should rather sit to the side, informing on systems to consider and supporting consideration of sequential and/or non-sequential representation.
- System descriptions will differ according to the assessment context and site characterisation will feed into this aspect, providing the foundation on site understanding.
- For exposure endpoints, both exposure groups and biota populations should be included and defined. The importance of the endpoints in terms of stakeholder communication should be made clear.
- Supporting the development of models (conceptual and mathematical) and data requirements is an area that is to be further discussed during the 2017 WG6 Technical Meeting and should be a key focus area for that meeting. This then needs to follow through to how to undertake calculations and communicate results. Consideration needs to be given as to what guidance and examples can be drawn upon to develop recommendations on how results can be communicated.
- It has not yet been bottomed out as to whether FEP lists are useful and further consideration needs to be given as to whether the enhanced methodology should include enhanced FEP lists and, if so, what to say about these. For example, the FEP lists have been found to be useful as a confidence building step for site-generic assessments. Work on FEP lists is ongoing in the NEA and we should be careful not to duplicate this work. One aspect that could be considered is whether it is possible to assign spatial aspects to the FEPs.
- There has been considerable experience of near-surface site investigations since 2001, how these investigations support assessment models and shape the way that the biosphere itself is

considered. The enhanced methodology needs to incorporate this experience and reflect it throughout, including the use of analogue sites. The site understanding is also a component of environmental impact assessments and defining boundary conditions for other components of the disposal system, which sit to the side of the methodology.

- Data and model selection principles are a topic to be discussed at the next WG6 Technical Meeting. A data protocol is included in the original BIOMASS methodology, but how much people use this protocol is unclear and hence it should be discussed, along with identifying any revisions that would be useful.
- It would be beneficial to highlight the usefulness of engaging with geosphere assessment teams, since discharge locations may help to define the assessment area and site characterisation programmes. Including lessons learned from SKB, Posiva and others may be helpful to others at earlier stages of their programmes. It should be recognised that the interaction with the geosphere is not just in relation to discharge locations, there will be feedback from the biosphere to the geosphere (e.g. recharge areas) and also gaseous emissions. Allowing a site to tell the story is an aspect that should be captured.
- For climate and downscaling, it would be nice to have a non-UK example to increase confidence in the projections that have recently been undertaken. It may be worth reaching out to the climate-change community to show the work that has been undertaken in support of MODARIA I WG6 and discuss approaches.
- There has been considerable experience in evaluating landscape development and thought should be given as to what would be appropriate examples to include in the enhanced methodology. This is to be further discussed in the next WG6 Technical Meeting.
- As noted in Section 3.1, a questionnaire will be developed to extract experience relating to principles for critical group selection. The questionnaire will also aim to extract information relating to environmental protection.
- A new section (or appendix) on managing uncertainty is to be developed with advances in capabilities and experience being captured.
- An example of iteration in site characterisation in support of assessments would be useful. This should highlight the degree of iteration both within and between different assessment cycles and illustrate how iteration has worked in practice.
- The concept of ‘intelligent Kds’ can be used as an example of a research model that may support assessments, helping to conceptualise what is happening and what is important. It is to be made clear that, as such approaches are in their infancy, they may be used to support assessments, but it should not be suggested that they must be used.
- The BIOMASS methodology is to support the development of biosphere assessments as input to safety assessments. It is not intended to provide a methodology for site characterisation, but site characterisation is an important input to BIOMASS. It may therefore be worth considering the development of a similar guidance document to support site characterisation programme development.
- Presentations from other biosphere modelling teams should be invited for the next meeting, to help ensure that the same programmes are not always the focus of attention and to ensure greater

sharing of experience. All participants of WG6 will therefore be encouraged to present their programmes to the broader group and provide perspectives on what is needed and helpful in going forward.

Specific actions set for the BIOPROTA TST and others are as detailed in the following table.

Action	Person(s) responsible	When
Draft interim update of the methodology	BIOPROTA TST, with lead from Russell Walke	November
Review the assessment context and identify where there have been changes that should be captured	All	For discussion in November
Development of questionnaire on potential exposure groups	Graham Smith and Lise Griffault (input from Karen Smith if biota included)	November
Update on international guidance within the assessment context	Graham Smith	November
New section on uncertainties	Rodolfo Avila	November
Provision of spatial mind-map and discussion around the use of a bottom-up assessment approach	Ulrik Kautsky and Ari Ikonen	November
Development of a conceptual illustration of where the biosphere sits within the overall system and how this relates to the methodology	Tobias Lindborg and Mike Thorne	November
Development of an agenda for the November Technical Meeting of WG6, capturing the actions detailed above and identified discussion and presentation topics, including inviting participants to present on their programmes	Russell Walke and Tobias Lindborg	October
Consider possible examples that could be used to illustrate specific parts of the methodology	All	For discussion in November
Identify potential location for shared files (including workshop presentations).	BIOPROTA TST and Tobias Lindborg	November

In addition to the specific actions detailed above, discussion topics were identified that are to be used during the next Technical Meeting to promote discussion amongst participants. These include the following.

- The role of FEP lists and interaction matrices. SKB have a generic interaction matrix that is inclusive of all processes for informing site understanding and could be used as an example. A further example of an interaction matrix is available from the BIOPROTA 2014 geosphere-biosphere report. Many assessments have made use of interactions matrices and provide a further source of illustrative examples.

- Model development and data selection principles. Russell Walke can lead on generic model development, but more site-specific experience is required from others. Mike Thorne will provide input around model development for Yucca Mountain.

- Data protocols, their usefulness and revision areas.

- Communication and stakeholders. Graham Smith will take the lead, reviewing whether experience demonstrates that the whole system is used in communication or whether there are examples where the biosphere has been specifically used. Experience could include that from legacy sites.

The BIOPROTA TST is to provide a draft interim report for discussion during the next meeting in November. This is to provide a clear view of the structure of the enhanced methodology in moving forward within WG6. The report will be issued as a BIOPROTA report, but noting the cooperation with the IAEA programme. The report will document progress at that time, re-iterating the continuing relevance of the main features of the methodology, illustrating its use and presenting enhancements, again with illustrations. Remaining areas for clarification are also to be identified. These will be examined further within the continuing MODARIA II WG6 programme of work. During the next meeting, consideration can be given as to additional examples that can be used to illustrate particular areas and presentations could be invited during the meeting on those possible examples.

APPENDIX A. MEETING PARTICIPANTS

The workshop was attended by the following participants.

Participant	Organisation
Ryk Klos	Aleksandria Sciences
Lise Griffault	Andra
Alexander Diener	BfS
Danyl Perez-Sanchez	Ciemat
Mara Watson	Clemson University
Jürgen Hansmann	ENSI
Ari Ikonen	EnviroCase
Joanne Brown	Environmental Radioactivity Consultancy
Rodolfo Avila	Facilia
Koen Mannaerts	FANC
Graham Smith	GMS Abingdon
Andre Rubel	GRS
Gerhard Pröhl	IAEA
Rodolphe Gilbin	IRSN
Donghee Lee	KORAD
H Jung	Korea Institute of Nuclear Safety
Alex Proverbio	LLWR
Mike Thorne	Mike Thorne and Associates
Andreas Poller	Nagra
Sanae Shibutani	NUMO
Neale Hunt	NWMO
Lauri Parviainen	Posiva
Kelly Jones	Public Health England
Russell Walke	Quintessa
Karen Smith	RadEcol Consulting
Emma Johansson	SKB
Tobias Lindborg	SKB
Peter Saetre	SKB
Ulrik Kautsky	SKB
Maria Norden	SSM
Shulan Xu	SSM
Reda Guerfi	STUK