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 Seventh Workshop Held in Parallel with the Third Interim Meeting of MODARIA II Working Group 6

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Version 2.0, 11 October 2019

PREFACE

BIOPROTA is an international collaborative 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 radioecological and other data and information issues that are common to assessments required in many countries. Collaboration through projects focused on mutual research needs is intended to make efficient use of skills and resources, and to provide a common, transparent and traceable basis for the choices of modelling approaches and parameter values, as well as 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 provide a forum for exchange of information to support the resolution of key issues in biosphere aspects of assessments of the long-term impact of contaminant releases associated with radioactive waste disposal and contaminated land management; and,
- to make available the best sources of information to justify modelling assumptions made within long-term safety assessments.

Particular emphasis is placed on key data for the assessment of long-lived contaminant migration and accumulation in the biosphere, and the associated impact, following discharge or release to the surface environment. 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 collaborative 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 held jointly with the third Interim Meeting of Working Group 6 (WG6) of the International Atomic Energy Agency (IAEA) second phase programme concerning Modelling and Data for Radiological Impact Assessment (MODARIA II). The meeting was held at the offices of BfS in Munich, Germany, from 15-17 May 2019. The objectives of WG6 are consistent with those of the BIOPROTA project, and the two projects met together to facilitate the sharing of knowledge and experience and to help coordinate parallel work, avoiding unnecessary duplication of effort.

The BIOPROTA project for review and enhancement of the BIOMASS methodology in 2019 has received financial support from Andra (France), DSA (Norway), ENSI (Switzerland), NWMO (Canada), Posiva (Finland), RWM (United Kingdom), SKB (Sweden), and SSM (Sweden).

Version History

Version 1.0: Draft workshop report prepared and internally reviewed by the BIOPROTA Technical Support Team to the BIOMASS enhancement project based on participant contributions prior to distribution on 14 August 2019 to workshop participants and BIOPROTA project sponsors for comment.

Version 2.0: Finalised after feedback on Version 1.0; distributed on 11 October 2019 to workshop participants, BIOPROTA members and WG6 participants.

CONTENTS

1. INTRODUCTION

The seventh BIOPROTA workshop, held in parallel with the third Interim Meeting of MODARIA II Working Group 6 (WG6), on review and enhancement of the BIOMASS methodology, was hosted by BfS in Munich, Germany from 15th to 17th May. The workshop began with a short introduction to BfS from Martin Steiner, followed by a welcome from Tobias Lindborg, chairman for WG6.

The successful way in which the BIOPROTA project has helped to facilitate international collaboration and support the technical effort required to review and enhance the BIOMASS methodology was acknowledged, facilitated by the support and sponsorship provided throughout the course of the project.

1.1 WORKSHOP OBJECTIVES

The main objective of the overall work programme is to support an international review and enhancement of the BIOMASSS methodology, leading to an updated version of the report describing the methodology supported by new examples based on real assessment contexts. The purpose of the methodology remains as in the original BIOMASS project, i.e. to provide a practical methodology for the assessment of the long-term safety of repositories for radioactive waste.

The aim is to retain the original basic methodological steps, i.e. not to change the overall approach, but to bring it up-to-date, based on new information, experience in its application, revised international recommendations and regulatory practice.

A draft report providing an enhanced BIOMASS methodology was issued in 2018 as an interim version and has been further developed, with an updated draft that was distributed prior to the workshop. This latest version takes account of comments and input from project participants on the interim version of the report. The primary objective for the workshop was to reviewing the latest version of the report with a view to its being updated to a draft final version as input to the subsequent fourth annual MODARIA II Technical Meeting 21st to 24th October. Remaining issues and gaps in the methodology were to be identified and associated actions assigned, noting that an appropriate level of ambition would be required in light of the intention to finalise the report by the end of 2019. In finalising the report, appropriate linkages to other IAEA work programmes should be made, noting that biosphere assessment is just one part of an overall safety assessment and safety case. Relevant IAEA activities relating to radioactive waste management and safety assessments were presented by Andrey Guskov (IAEA).

1.2 WORKSHOP PARTICIPATION

The workshop was attended by 24 participants from 10 countries. Participants and their affiliations are listed in Appendix A.

1.3 REPORT STRUCTURE

Section 2 of this report summarises the presentations from workshop participants and associated discussions. Section 3 then summarises key discussion points and actions arising from walking through and discussing the various sections of the draft report. Next steps are summarised in Section 4.

2. PRESENTATIONS AND DISCUSSIONS

Presentations from workshop participants and associated discussions are summarised below. Presentations comprised both feedback following review of the draft report and specific topics being addressed within sections of the methodology, including appendices. The focus of reporting has been on capturing further comments and revision requirements for the next iteration of the report.

2.1 CURRENT STATUS OF THE METHODOLOGY

Russell Walke (BIOPROTA project Technical Support Team, TST) summarised the current status of the report.

Feedback has been received on the interim report from several participants/organisations and further feedback is anticipated. The feedback is vital in ensuring that the updated methodology reflects the experience of all participants, so as to achieve the widest possible degree of buy-in to the results. Most of the feedback received to date has been incorporated in the version of the report distributed prior to the workshop. Remaining and additional feedback will be incorporated in the draft final report that will be distributed prior to the final Technical Meeting (TM) to allow for final review; the final Technical Meeting provides an opportunity for a final collective walk through of the report.

Generic reference biospheres are being replaced by pointers to real assessment examples and a table has been developed that will be included as an appendix to the report, providing a list of examples with the intention that descriptions of particular aspects that make those examples of interest will be developed. The 'owners' of the examples are requested to provide text and/or highlight which aspects of the assessments should be specifically noted. The examples should include not only operators' models and approaches, but also models and approaches taken by regulators in reviewing assessments. A further appendix will be developed that provides a synthesis of results from the questionnaire on potential exposure groups (PEGs).

There is scope to move more extensive 'appendix' material to a separate BIOPROTA report, as a supplement to the main BIOMASS methodology report, which is anticipated to be published as an IAEA TECDOC. The supplementary BIOPROTA report could, for example, include text on landscape evolution and identifying the area of interest, based on Posiva and SKB experience. Links should be provided to signpost further information of potential use to those tasked with developing and/or reviewing biosphere assessments.

Review of the use of the original BIOMASS methodology has shown that not everyone followed the exact step-by-step approach of the methodology, but most followed the overall structure, so a clear presentation and explanation of the work-flow is an important aspect of the enhanced methodology. This reflects the complexity of information flow in safety assessment for radioactive waste disposal facilities, taking account of how new information and other factors may vary with each stage of repository development[a].

[a] Similar experience and complexity is found in relation to assessments made in support of legacy site management are highlighted in an international workshop report (NRPA, 2018 - https://www.dsa.no/en/publications?p=2&s=3d), and in the context of near-surface disposal in and IAEA TECDOC 1814, of 2017.

Various iterations of the methodological figures have been discussed in previous workshops and revised versions developed for further consideration. For example, the figure illustrating interaction with the wider safety assessment and safety case has been revised to reflect that this is an overarching aspect. The figure showing system understanding at the centre of the iterative approach to developing biosphere assessments is accepted as being the preferred way to illustrate the overall steps. The alternative linear version of the figure will be moved to the sub-section describing the report structure[b]. As such, care is needed to ensure the report structure matches the linear figure, since the structure and terminology has developed through the different iterations of the report. Other figures throughout the report also need to be given due consideration, including the potential to develop some generic figures that illustrate how results can be presented.

The conclusions still require development and provided a topic for discussion during the workshop. There will be the opportunity for final discussions on the report during the last Technical Meeting (TM) of MODARIA II in October 2019 and any final revisions can be made to the report at that time. Prior to the TM, the final draft report should be shared with other IAEA project and working groups, including GEOSAF and PAGODA and MODARIA II WG1. Sharing with the latter would help in joining up the working groups for any future IAEA MODARIA-type of work programme. Context should be given to WG1 when submitting the report for their review to ensure the correct focus – this should be on the application of the methodology rather than editing.

The following particular topics were identified for consideration during the workshop.

- The methodology is intended to be fit-for-purpose, irrespective of the programme. It should be clear up-front that the method is intended as a guide on how to think through assessments rather than being a prescriptive method that must be followed.
- Ensuring biota dose assessment is captured in the assessment context and making clear that such assessments may not always be required, depending on the national regulatory position.
- Ensuring examples encompass both operator and regulator experience and cover the range of assessment phases, from site-generic through to site-specific, associated with repository development programmes to inform those new to the field.
- Consideration should be given to providing some guidance on how to use data and address data gaps. Potential sources of information such as IAEA Technical Report Series documents could be identified.
- Strengthening the report through the inclusion of more references.
- Screening criteria for identifying contaminants that should be quantitatively assessed is a topic that has not yet been covered in the report. The need for screening should be recognised and examples could be provided (e.g. FANC screening example). The term ‘screening’ may not be appropriate since it implies either ‘in’ or ‘out’ whereas the contaminants to include in assessments may change over time as inventories change (setting priorities for contaminants may be a better phrase).

[b] The linear and more realistic complex representations of the multifarious interactions associated with building a safety case as part of a wider management programme are highlighted in the first report of the NEA’s Expert Group on Legacy Management, currently in publication at NEA-OECD.

- Appropriate linkages should be made throughout the methodology to other aspects of the overall safety assessment and safety case, including links to the waste inventory.
- In terms of reporting and evaluation, peer review when finalising assessments/reports could be specifically mentioned.

2.2 ASSESSMENT CYCLES AND FEEDBACK FROM REVIEW OF THE REPORT

Ulrik Kautsky (SKB) introduced a new iteration of the methodology diagram that aims to illustrate that system understanding is central to assessments, where system understanding includes site data and understanding, past experience, and both general and scientific knowledge. The revised version of the diagram has been informed by recent experience in undertaking a site-generic safety evaluation for a low/intermediate level waste repository that has made use of data obtained through a site characterisation programme from a previously studied proposed repository location for spent fuel disposal.

The various programmes undertaken by SKB have illustrated how experience and analysis of results from one assessment feeds back into the next phase of assessment and how knowledge of site data informs ongoing site characterisation programmes etc. All the major working areas are very much interlinked. At no point does an assessment begin from a blank page, as there will always be some initial conceptual understanding of the system. The emphasis of assessments can, however, vary depending on the knowledge base that has been built up. For example, for the SR-Site assessment time was largely spent on developing site understanding and formulating models, whereas the focus for SR-PSU, which encompassed the same environment, was largely on exposure and transport modelling and appropriate application of data.

Discussion

The assessment context should be referred to regularly, irrespective of the stage of assessment and, therefore, it may be appropriate to include it in the central area of the diagram.

Some peer review and/or decision making/communication of results could be explicitly mentioned at the end of one cycle before feeding back into the assessment context for the next iteration, potentially with a break in the cycle to emphasise this stage. A range of stakeholders, including regulators, will review assessments within a stepwise implementation of the methodology and this would provide a natural break point.

The term ‘interpretation and application of results’ was suggested for the end point to an assessment cycle.

The requirements placed on the monitoring programme for a site are much larger than biosphere assessment needs and should not, therefore, be considered in isolation from the rest of the programme.

2.3 GENERAL COMMENTS FROM SKB

Björn Söderbäck (SKB) summarised feedback from SKB on version 1.1 of the report. Key points of feedback were as follows.

- The constraints set by regulations and the overall assessment context needs to have greater emphasis. The biosphere assessment context is part of the overall assessment context and this should be made clearer.

- Uncertainties are key in terms of confidence building and clear and consistent advice around best practise (including references) would be beneficial.
- The level of detail throughout the methodology would benefit from some harmonisation with less detail in some areas being useful for the reader.
- Uniform terminology is needed along with clear definition of the terms used. The IAEA terminology should be used where available with a web-link provided to the online version of the glossary, along with a version number to future proof the report against any changes in terminology over time.
- Assessments are an iterative process rather than sequential. Each step is necessary but may be revisited. Furthermore, it should be recognised that there can be more than one way of doing things. Ideally these points should be captured in the methodology and associated diagrams.
- The methodology would benefit from greater focus around the coupling between site data and biosphere modelling and the need for integration and cooperation on site investigation, site description and modelling. The use of simple parameters should be emphasised, in recognition of what people will readily understand and what can be measured.
- More focus is needed around model verification and, particularly, the investigation of results in relation to whether models are performing as expected. Whether or not results are understandable has implications for confidence building. Implementers should be able to demonstrate that they understand the models they are applying.

Discussion

In Belgium, there is a requirement for assessment reports to include a separate chapter covering all aspects of assessment uncertainties, including around the models applied, which helps assessors to consider the outputs of the models in the context of the uncertainties. This illustrates how the regulatory framework affects what is undertaken in assessments. The circular methodology diagram should explicitly include uncertainties: Section 2.3 has been revised to include management of uncertainties and this is to be reviewed to ensure appropriate aspects are covered with the diagram being aligned with this extended text, as appropriate.

In developing lessons learnt for the report, it would be useful to have feedback from regulators on what has been done in assessments they have reviewed, what has worked well and where more was needed. This would help identify where more effort might be required in finalising the enhanced methodology. Reporting of the dialogue between operators and regulators could be a useful topic to cover.

2.4 REVIEW COMMENTS FROM ANDRA

Emilie Aubonnet (Andra) provided some feedback on the November 2018 version of the report, from the perspective of someone new to the field.

The report is well structured with the different sections being clear and steps easy to follow, although the level of detail was not always consistent in the draft that was reviewed, with initial sections being the most detailed. The illustrations of the method are helpful.

The report would benefit from more examples, particularly with regard to conceptual and mathematical modelling and calculation and interpretation of results.

Illustrations of how results can be presented would be beneficial along with principles for developing understanding around results, what can be learnt, and discussion of when enough has been done in assessments or when further calculations may be required.

Inclusion of more information on the building of interaction matrices would be useful.

Thought could also be given to including lists of parameters required (or referring out to sources of information), such as those needed to support calculations relating to lifestyle habits.

Further guidance on selection of the release point from the geosphere to the biosphere would also be useful, along with information on what can be done when there are no natural release points.

Discussion

Careful thought is needed with regard to the inclusion of examples illustrating interaction matrices and their development into mathematical models to ensure the methodology is not seen to be endorsing particular approaches. It may be appropriate to reference out to a few examples to avoid such issues.

Decisions on parameters required for models is part of the methodology and it is not, therefore, intended that lists of necessary parameters would be provided. Some examples or an appendix could, however, be provided on the topic of data needs and application. For human habits, consideration could be given to the development of a paper discussing the types of parameters that may be needed that could support the methodology. Overall, consideration should be given to the development of papers on topics that would support the application of the methodology.

2.5 SIMPLE AND TRANSPARENT MODELLING APPROACH FOR BIOSPHERE ASSESSMENT IN POST-CLOSURE SAFETY ASSESSMENT

Reda Guerfi (STUK) presented an overview of a joint project undertaken by SSM and STUK, the intention of which was to simplify modelling concepts: if a similar output can be achieved using simple approaches to those of more complex modelling studies then this can help in building confidence.

Biosphere models translate radionuclide releases to doses or risks that can be compared against regulatory criteria. The complexity of models can be increased in moving from generic to site-specific assessments through, for example, consideration of climate change and ecosystem evolution. This is particularly relevant in the Baltic Sea coastal area, where land uplift will lead to the formation of lakes, mires and forest areas over time, requiring the succession of “biosphere objects” to be considered. Regulatory reviews of dose assessments from Posiva and SKB have been challenging as a result of the complex methods used to assess potential doses in changing systems. As complexity increases, greater justification is required, and the degree of confidence will be affected by the ability to explain and justify such approaches. Consideration of a simple and transparent approach is, therefore, required and led to the joint project undertaken by SSM and STUK.

For geological disposal facilities, groundwater discharge points to the biosphere will occur at the lower points in the landscape. All local topographic minima are therefore potential release points in these contexts. The hypothesis was, therefore, that future release “objects” could be identified through a statistical analysis of topographical site data from the current landscape.

A three-stage approach has been developed. Initially, GIS techniques are used to identify the spatially individual sub-catchments within an area. Biosphere objects are then identified within the sub-catchments, with lakes, rivers and wetlands occurring in the local topographic minima. Statistical analysis is then used to evaluate uncertainty around object sizes. A generic ecosystem model approach

(GEMA-model) has been developed that can be used in the final stage to evaluate the uncertainty around the time of transition to different types of object (e.g. agricultural land). The approach is described in more detail in Guerfi et al., 2019[c].

A comparison of approaches has been undertaken for the Forsmark site for four radionuclides. The time of transition of landscape objects to agricultural use affects doses, with the doses being lower for those objects transitioning earlier in time due to the reduced time for accumulation of radionuclides. Agricultural land persists on former mires for a few hundred years at the maximum. For radionuclides with higher Kd values, higher doses occur for smaller biosphere objects; if the catchment size increases by an order of magnitude, then dose decreases by one order of magnitude. For radionuclides with a low Kd value, higher doses occur when object and catchment size are equal.

The proposed approach has been concluded to be both straightforward and transparent in identifying biosphere dose objects. It is considered to help build confidence in assessments and allows uncertainties relating to safety critical issues to be explored.

Discussion

The selection of objects is based around low topographic areas with all objects that could support a small agricultural community being selected, i.e. areas of 10^4 m^2 or greater. The topography informs on where water is most likely to go. The approach could be applied to alternative real sites to see whether or not it is more widely applicable. Lowland Britain could provide an interesting comparison. The approach could be applied and compared against current gauged discharges from instrumented catchments.

The method has not yet developed to consider landscape development, e.g. erosion effects, but this is something that will need to be considered. Some information on the evolution of rivers in the United Kingdom is available from the British Geological Survey.

2.6 SITE EVOLUTION AND IDENTIFYING AREAS OF INTEREST

Ryk Klos presented detailed material originally developed for a potential appendix to the BIOMASS report. The material is closely linked with the presentation given by Rueda Guerfi (Section 2.5). Overall, the approach is intended to be relatively simple, based on present-day topography and the identification of areas in the landscape where natural discharges of deeper groundwaters could occur due to the low topography.

Given the aim of streamlining the BIOMASS report, the material may be further developed into three papers for publication in the scientific literature and summarised in the accompanying BIOPROTA publication. The intention is to summarise developments over the last decade or so in terms of how datasets are interpreted and the use of expert judgement to inform on what data is saying about a site.

Posiva have a GIS-based software tool (UNTAMO) that supports the identification of landscape objects in a complementary fashion. If UNTAMO provides similar results to the relatively simple approach developed on behalf of STUK and SSM, then this will help to provide confidence in defining biosphere

[c] Guerfi R., et al (2019). A simple and transparent modelling approach for biosphere assessment in post-closure safety assessment. IHLRWM 2019, Knoxville, TN, April 14-18, 2019.

objects for similar contexts. The approach requires relatively few resources as a first approximation with more being able to be done if resources allow.

Discussion

UNTAMO is a collection of present-day standard GIS tools that are readily available and so are no less accessible to those new to the field; both approaches are therefore considered to be relatively accessible. The focus should not be solely on assessment tools; description of the system and ensuring this is consistent over time is important in interpreting how the system works and what could happen in the future.

The intention of the BIOMASS methodology is to describe what needs to be done and guidance on how that can be achieved, rather than recommending one specific approach over another. For example, some concern was expressed that the examples/approaches described here are focussing on fractured granitic bedrock areas in Nordic regions. The issues can differ for sedimentary rock contexts that may need to be considered in a different way (e.g. natural discharges of deeper groundwater are not the reference case for other assessments, for whom groundwater abstraction from confined aquifers may be of primary interest).

Moving this material to supporting publications is intended to find balance between presenting guidance on an overall methodology that can be used consistently in a range of different contexts, as well as signposting further experience and approaches that could be of relevance.

2.7 IAEA, MODARIA AND WG6 INFORMATION

Andrey Guskov (IAEA) presented.

Long-term safety is the focus of a safety case and has to be considered from the very initial stages of assessment programmes when little is known about a facility, since this helps inform site selection etc. However, the level of conservatism and detail in supporting assessments changes over time as programmes develop and more understanding is gained.

In the overall safety case, the system description demonstrates system understanding and provides the basis for assessment. It should include information on the facility design and its selection and cover the near-field (inclusive of the waste itself, engineering and the zone affected by construction), far-field and the biosphere. The biosphere is therefore an important part of the system and its description should encompass present-day, operational and the long-term post-closure phase, with evolution over time.

The national context is very important for assessments, providing focus in terms of national laws, policy and strategy for radioactive waste management. Requirements for radiation protection and environmental protection are also important, providing the basis for the safety “envelope” that feeds into the safety case.

In February, a joint meeting was held between members of the ongoing IAEA GEOSAF II project and WG6. Part II of the GEOSAF project was established to address the interface between the operational and post-closure safety and, more specifically, to elaborate on a structure and methodology to define an overarching safety case supporting the demonstration of safety of geological disposal, integrating both the operational and post-closure phases.

Monitoring is an important aspect that is linked to long-term safety and the “design target” for a facility. Monitoring relates to more than just radiation and radioactivity, it also encompasses aspects of the environment that could affect safety, including groundwater characteristics etc. Broader issues relating

to long-term safety and assessment therefore need to be considered when thinking about monitoring and a sub-group has been established within GEOSAF II on the use of monitoring programmes in the safe development of geological disposal facilities for radioactive waste. The objective is to evaluate the role of technical monitoring information in supporting decision making, in relation to other inputs, and how decisions can be justified based on such monitoring.

The IAEA HIDRA project on inadvertent human intrusion aimed to develop a general approach to consideration of potential human intrusion within safety cases for radioactive waste disposal and to test and illustrate its practical application through hypothetical examples. Inadvertent human intrusion is not a simple yes or no issue in decision making; it can feed into waste acceptance criteria and facility design optimisation. For near-surface facilities, the greatest hazard associated with human intrusion is associated with bringing waste to the surface environment. For deep geological facilities, the greatest hazard may be associated with creating potential release pathways.

Ideas for new collaborative projects/working groups are invited by the IAEA. Broader participation in ongoing IAEA programmes is also very welcome.

Discussion

One aspect that is often forgotten with regard to monitoring programmes is that the biosphere will change over time. Furthermore, measurement techniques will evolve, such that it may be appropriate to archive samples to account for likely monitoring and analysis technique developments into the future. Monitoring strategies should therefore acknowledge that changes will occur that have nothing to do with the disposal facilities themselves.

It should also be recognised that the biosphere interacts with the facility. For example, the chemistry of soil layers can affect the deeper geochemistry, which can in turn affect the near-field. The different systems should not, therefore, be considered in isolation. Artificial separation of the biosphere and geosphere should be avoided, with integrated consideration being given to the engineered system and the natural system.

Monitoring programmes should also not solely focus just on the immediate area around a facility, since the wider area can affect the facility and because potential impact may arise outside its immediate vicinity.

2.8 POTENTIAL EXPOSURE GROUPS AND POTENTIALLY EXPOSED POPULATIONS OF BIOTA

Graham Smith (project TST) presented a summary of the questionnaire on potential exposure groups (PEGs) and potentially exposed populations of biota (PEPs) that was distributed earlier in the project, along with some conclusions for the report.

Various assumptions need to be made when considering the most exposed group. For example, thought needs to be given to different groups that may be maximally exposed to different contaminants. The notion of PEGs, therefore, needs to be emphasised and consideration given to different exposure pathways before identifying the most exposed PEG. It should also be remembered that the focus may not always be on the most exposed PEG; stakeholder interests may provide a driver for considering alternative PEGs, such as city dwellers. It should also be remembered that all exposure groups in long-term assessments are hypothetical.

For the Andra Cigeo assessment, a habits survey for the present-day provided the basis for PEG habits. For future behaviour, some habits were increased, such as water consumption from the area of interest. Care was, however, taken to ensure increased habit assumptions were not physically unrealistic.

Assumptions about PEGs can influence assessments. For example, in some assessments the drilling of wells is considered as part of the reference case/normal evolution, whereas for others it is considered part of inadvertent human intrusion. How such aspects are considered in assessments affect the associated constraints applied and distinctions are made based on the context and the safety strategy.

The spatial areas of interest in assessments can vary depending on whether contaminant transfer is via groundwater or as gas. This will also affect selection of PEGs and should be noted in the methodology. Consistency in habit parameterisation (e.g. breathing rates) should ideally be maintained if different pathways are assessed separately.

ICRP guidance on PEGs for the post-closure phase is for adults to be the focus of assessments. Regulators and other stakeholders may, however, have interest in seeing that other age groups have been explicitly considered; there are several examples of assessments that have chosen to include infants and children for this reason. It was noted that care should be taken to avoid being prescriptive in developing guidance. The draft report states that other age groups may be assessed for “comparison purposes”, but this may be better as “compliance purposes”, noting the importance of the assessment context.

In terms of biota PEPs, it should be made clear in the introduction to the method that the same biosphere model could be used for assessing PEGs and PEPs, but that the temporal and spatial averaging within the biosphere area of interest may differ. An illustration could help show the difference. It may also be worth noting that assessment parameters within biota dose assessment tools, such as ERICA, should be revised to be consistent with the overall biosphere assessment (e.g. Kd values).

Correlations need to be adequately considered in relation to the guidance on PEGs and PEPs.

2.9 EXPERIENCE IN THE INTERPRETATION OF RESULTS AND LESSONS LEARNED

Lise Griffault (Andra) shared recent experience at Andra of the evaluation of an on-going safety case. Unexpected results were obtained for one radionuclide; whilst it was recognised that something was wrong, it was difficult to ascertain why. Collaborative work was undertaken to check and verify all data from the inventory through to transfer data for the surface system. Two issues were identified: a mistake had been made with transfer data and some data were overly conservative for the scenario.

The integrated approach to identifying issues across the assessment was useful, allowing the entire chain of transfer from the near field through to biosphere dose assessment to be considered. It is a good illustration of iteration within assessments and the importance of allowing for assessment findings to be fed back, such that experience and knowledge in terms of important pathways and habits can feed back to the inventory and waste acceptance criteria.

French regulations require dose to adults, 10-yea-olds and 1-year-olds to be evaluated. Results of analysis have shown that the important radionuclides for dose can vary between these age groups as a result of differences in eating and drinking habits. Analysis of the differences has allowed a clear explanation to be developed, which was important for communication both with regulators and members of the public.

In terms of the BIOMASS methodology, the following suggestions were made:

- suggestions around the presentation of results could be made, though these would have to be generic rather than focussing on specific assessments;
- the circular methodology diagram should include iteration back to waste acceptance criteria and assessment context; and
- the need to feedback from one assessment to another should be emphasised.

Discussion

Whether or not parameters in assessments are conservative or not can be difficult to determine. For example, Kd values may result in radionuclides being retained in the geosphere, thus reducing dose from those radionuclides, but this could give rise to the build-up of daughter radionuclides that then increase dose. Probabilistic assessments can help, but tools need to be applied with appropriate knowledge.

3. WALK THROUGH OF THE DRAFT REPORT

The various sections of the report were reviewed to elicit further feedback from workshop participants and to help identify actions to support finalisation of the report. This section documents particular points of note arising from discussions, where these are not already adequately captured in Section 2.

Many of the points raised were addressed during the workshop, but checks are to be made when finalising the report to ensure they have been adequately covered.

3.1 OVERALL REPORT

- There are some particularly long sections present throughout the report and consideration should be given to revising to remove unnecessary detail and the use of further sub-sections to help structure the points.
- The report would benefit from more figures to illustrate aspects of the methodology.
- Unnecessary words throughout the report are to be removed, for example, removal of 'not to say impossibility' within Section 2.
- Throughout, stronger referencing is required whilst avoiding appearing to endorse specific approaches. An action was placed on all to review the report and provide references, as appropriate, to illustrate different areas of the methodology.
- Justification runs throughout the entire methodology and, wherever appropriate, the need for decisions to be documented along with supporting reasoning should be highlighted.

3.2 SECTIONS 1 AND 2 (INTRODUCTION AND ASSESSMENT CONTEXT)

- The introduction should be updated to note that examples for the different steps of the methodology are provided in an appendix.
- Site data comprises more than just the surface system. It could, for example, include near-surface hydrology and/or particle-tracking data used to identify the area of interest etc. Clarification is therefore needed as to what 'site data' means in the context of the methodology. Similarly, site characterisation can include information required for biosphere assessment, but also for all other aspects of making a safety case. Discussion is provided in Box 1 and should be reviewed to ensure these points are adequately covered.
- There are times where text refers to post-closure safety case (e.g. paragraph 1), but there is also interaction with the operational safety case. Where appropriate, the text should be changed just to safety case.
- The term 'coherent' was suggested to replace 'consistent', which may not be appropriate in all instances. Care should be taken in using the term 'essential'.
- In Section 1.2, there was a bullet list relating to Example Reference Biosphere 2. There was some concern that the information within this list and the subsequent paragraph could be considered by readers as being intended as a benchmark, which is not the intention. It was therefore suggested that the list and subsequent paragraph be removed, but with some alternative text provided to give a short historical timeline.

- Consideration is needed as to whether a list is required of what has changed in the methodology since the original was developed.
- Within the terminology section, the biosphere is now distinguished from characteristics of the actual site, with biosphere being reserved for assessment purposes. Within 'safety assessment', the phrase 'including the post-closure phase' is to be removed since the method may be more broadly applicable. This is to be made consistent throughout the methodology.
- FEP lists will not be included within the enhanced methodology since they are available elsewhere.
- The linear version of the methodology will be included within a section on report structure
- Within the cyclical methodology figure, a box for external review/evaluation could be included, potentially being placed outside the methodology circle to emphasise the need to stop and think, as well as highlighting the need to interact with the overall safety case (consistent with Figure 1).
- The assessment context should be continually referenced, so may merit being placed in the centre of the circular methodology diagram.
- The descriptions of source term and geosphere biosphere interface (GBI) should be brought forward from Section 2.5 into terminology. The source term is normally considered as the waste inventory but can be used in terms of the GBI. A clear definition is required. The term 'biosphere source term' was suggested.
- 'Non-radioactive contaminant' should be used in place of 'toxic'.
- Biosphere assessment supports rather than provides proof of concept. The terminology section should, therefore, be revisited to ensure that this is captured.
- Assessment endpoints are not just calculated doses (the methodology refers to contaminants rather than radionuclides). Wording requires revision, particularly ensuring any implication of a 'need' for including chemicals or biota assessment is removed.
- The assessment philosophy (Section 2.3) should be for the overall approach, with links through to the safety case. This component of the assessment context was part of the original methodology and should therefore be retained, but it is specifically about whether the objective of the assessment is to make a cautious or realistic evaluation of the endpoints, and hence how that affects the management of uncertainties[d]. The use of the term philosophy is consistent with SSG-23 and this should be maintained, but some revision may be warranted, such as the use of the phrase 'overall approach to management of uncertainty (philosophy)'.
- The paragraph on 'restrictions on the pathways of exposure' was agreed to be removed.
- Some detail within Section 2.4 on the disposal system and site context could be removed and replaced with references to examples. More balance is required between the disposal system and

[d] As noted in the original BIOMASS methodology, realistic assessments should be used in achieving optimisation and in comparison of options, whereas, if the intention is to show that a particular endpoint value has not been exceeded, then cautious assumptions may be more appropriate.

site context with equal weighting being given at present. This section should appropriately capture the need within assessments for assumptions to be clearly captured.

- IAEA terminology should be consulted to ensure appropriate terms are used with regard to the 'disposal system', since there can be different meanings for different contexts.

3.3 SECTION 3 (REPRESENTATION OF THE BIOSPHERE)

- Section 3 links back to the scenarios being considered in the overall safety case and this link needs to be clear.
- A list of principal characteristics was provided in the initial methodology that relate to climate, topography etc. For the revised version, it was suggested to call these just characteristics (losing 'principal'). Greater linkage to timeframe should be included since biosphere evolution is very much linked to timeframe. This link should be emphasised within the section on assessment context.
- The location and extent of the assessed biosphere is difficult to define if there is no background information on the repository and flow paths to through the geosphere, with the risk that the wrong assessment area could be identified. The starting point should, therefore, be a description of the broader regional biosphere.
- The decision tree to support decisions around whether or not landscape evolution is to be addressed is helpful and should be linked to the MODARIA I WG6 report.
- The diagram contained within Box 2 has received some criticism for not giving adequate information on processes. This has been redrawn and complemented by updated text.
    - Human activities are not explicitly represented in the figure, but are referred to in yellow boxes; the overall figure is intended to illustrate how external FEPs (e.g. global climate variation) can be propagated to the biosphere, whereas human influences are considered more in terms of regional influences on the local context.
    - Red arrows in the diagram are intended to illustrate that everything in one box influences the next. A linkage to the report of MODARIA I WG6 is required along with information on the availability of the updated climate model that was used in that work.
    - Working group participants are specifically invited to review the new version and to provide feedback.
- The removal of Box 3 was recommended, since the content of this box will now be covered in appendix examples. Those examples should include a range of examples that illustrate the different timeframes of interest (e.g. through reference to SKB assessments for different repository programmes).

3.4 SECTION 4.2 (HUMAN EXPOSURE GROUPS AND POTENTIALLY EXPOSED BIOTA POPULATIONS)

- Feedback from the PEGs questionnaire should be drawn into the text to balance out the quantity of guidance provided on PEGs with that available for potentially exposed populations of biota (PEPs).

- Consistency in assumptions made for PEGs and PEPs should be highlighted, where appropriate, such as the presence of foods such as fish for human consumption and the species of PEPs considered.

- The guidance on PEGs and PEPs will not be further developed to provide detailed guidance with respect to non-radioactive contaminants and associated criteria. An introductory paragraph should, however, be developed to provide explanation and set the scene for the sections on PEGs and PEPs. This should link back to the assessment context components relating to this topic, to ensure consistency. Reference to the BIOPROTA reports on radioactive and hazardous waste assessments may be appropriate.

3.5 SECTION 4.3 (CONCEPTUAL MODELS)

- Alternative approaches to the use of interaction matrices for supporting the development of conceptual models should be explored.

- The interaction matrix for RWM's biosphere model will no longer be presented in Box 5, as it will be sign-posted from the examples appendix.

- A simple interaction matrix could be included as an example (e.g. Figure C8 from the original BIOMASS report). Some text describing generic principles and how to read such matrices could be useful, highlighting that these matrices are aimed at describing contaminant transfer through a system and can be useful in ensuring that nothing important is missed when developing assessment models.

- The broader potential usefulness of interaction matrices could be noted, since they may also help provide structure to the system description, as well as facilitating conceptual model development. The BIOPROTA report on defining and assessing the geosphere-biosphere interface provides useful illustrations of interaction matrices being used from initial conceptualisation through to transport modelling.

3.6 SECTION 4.4 (MATHEMATICAL MODEL DEVELOPMENT)

- Mike Thorne and Ryk Klos have developed a paper on the development of mathematical models that is in the process of being finalised prior to submission. The paper refers to the use of interaction matrices in the development of transport models with the matrix lead-diagonal elements (LDE) becoming the compartments of the model and the off-diagonal elements being the processes that operate between the compartments. The LDEs can also be split into groups of computational elements that are essentially sub-models. The computational representation of the processes and methods of solution are also covered. The draft paper has been distributed and comments are invited from participants. The paper will be submitted in time to ensure it can be referenced in the report.

- More detail is required around what is needed in terms of building toward a mathematical model and how this can be approached. It may be useful to include a simple illustrative case that shows the approach to developing a mathematical model from an interaction matrix through the use of equations.

- The current section of the report includes an equation that relates to a dynamic system with text then describing non-dynamic systems and how they can be addressed. Sub-sections are being used to illustrate some of the known pitfalls. Pulse releases are not yet included but have been considered in the paper developed by Mike Thorne and Ryk Klos. Consideration of short-term

releases should be added to the report itself, noting that consideration of pulse releases would affect the conceptual model and its computational representation.

- The need for timeframe to be considered with regard to biosphere dose conversion factors should be made clear (noting that equilibrium may not be reached given the timescales of contaminant releases and of system change). This should link back to the assessment context and decisions on timeframe and sequential or non-sequential approaches. Additional text may be required overall around the use of biosphere dose conversion factors.

3.7 SECTION 4.5 (APPLICATION OF DATA)

- The data protocol aims to guide assessors to focus on the data that are key for assessments and text has already been revised to avoid the implication that formal expert elicitation is required.

3.8 SECTION 4.6 (IMPLEMENTATION, VERIFICATION AND VALIDATION)

- There is some overlap between this section and Section 5, which needs to be reviewed and addressed.

3.9 SECTION 5 (MODEL EVALUATION AND COMMUNICATION OF RESULTS)

- Section 5 has been further developed, based on information presented during previous workshops. Feedback is therefore invited.

- The emphasis of the section is on the need for iteration and management of uncertainties, for review of model output to ensure that it is in line with expectations and, where this is not the case, for results to be evaluated to identify why.

- Evaluation and explanation of results is an important contribution to building confidence in the assessment. For new assessments, it may be difficult to know what to expect, but experience from other programmes can be used to indicate what radionuclides and pathways may be expected to dominate. The example of Mo-93 being identified as a new radionuclide of importance in SKB assessments for SFR and SFL illustrates how review of assessments can lead to new radionuclides of interest that had not been expected.

- Some guidance around putting results in context is needed. This should include demonstrating compliance, but also providing reassurance to stakeholders on topics they care about. Complementary indicators should also be covered, as should the need for judgement in presenting results. For example, it may be appropriate to say ‘no impact’ or similar rather than presenting incredibly small numbers.

- The section would benefit from examples that illustrate the calculation and interpretation of results.

3.10 SECTION 6 (CONCLUSIONS)

- Participants were requested to review the report and provide points that should be covered in this section. Further discussion around conclusions will be needed to finalise this section during the Technical Meeting in October.

- It should be emphasised that the methodology is intended as guidance and is not prescriptive.

- A bullet list could be developed that summarises the key updates to the methodology, such as the amount of work undertaken on climate and environmental change, the development of assessment

approaches for biota, and the development of capabilities with regard to probabilistic modelling since the original methodology was developed.

- More could be made around the usefulness of the methodology, given the number of examples that illustrate different aspects.
- The integration of the biosphere within the overall assessment, rather than being considered as a measuring stick, could also be drawn out (ensuring this is also clearly stated at the front end of the report). Biosphere assessment will always include some aspects that are independent of the overall assessment, such as PEGs and PEPs, but the overall approach to biosphere assessment should be consistent with the assessment of the full disposal system where appropriate.
- The fact that the methodology is not restricted to application in long-term assessments, but can also be applied to operational phases, should also be highlighted. It may be worth noting that the lessons learned and techniques applied may also have broader application, such as to legacy site contexts.

3.11 APPENDICES

As discussed above, detailed appendices will be moved to a supporting BIOPROTA publication, leaving appendices on the PEGs/PEP questionnaire and providing examples of biosphere assessment studies in the main BIOMASS methodology report.

Examples Appendix

- The table of examples is to be further developed such that it covers all aspects of the methodology, without appearing to endorse any particular approach.
- A broad spectrum of examples will be required that cover as many different contexts as possible. Examples and guidance for sedimentary contexts are required to balance those provided in relation to fractured granitic bedrock from Nordic regions. The MODARIA I WG6 report (Figure 2.1) includes different types of contexts for repositories and this can be used to help ensure that a wide range of contexts is covered (geological, near-surface and surface disposals and both generic and site-specific assessments). For example, disposal in salt formations should be included, with reference to WIPP.
- References are required for each of the examples with specific sections of reports or sub-reports (and/or scientific publications) being identified that illustrate the particular aspects of the methodology that are well illustrated.
- Regulatory reviews, particularly where they include model development, should also be captured.
- Examples of wider safety case integration and how the biosphere has been handled in terms of public engagement would also be useful.
- Those responsible for different assessments should draft the text for inclusion within the appendix. A template for appendix examples is to be developed by the TST and distributed to participants with responses being collated prior to finalising during the October Technical Meeting.
- A matrix of the topics covered by each of the examples could also be developed to aid readers in navigating through the appendix.

Uncertainties

- Text on uncertainties is being developed by Ari Ikonen for inclusion in the supporting BIOPROTA publication.
- This material will cover data and the management of uncertainties, with reference to knowledge quality assessment.
- The introduction will provide a roadmap to further sources of information. Pedigree analysis will be introduced, and illustrations provided as to how it can be applied to various aspects of assessments. A model uncertainty chapter will cover conceptual, mathematical and numerical uncertainties as well as the use of alternative models and the qualification of models. Sensitivity analysis will also be covered as a means of identifying the uncertainties that matter in assessments. The current draft is around 40 pages. The level of detail is somewhat variable and further work is intended over the summer to address this prior to distribution in August for comments.

Material on Identifying Areas of Interest, Site Characterisation and Site Analogues

- Text on site characterisation has been developed based on experience from the Swedish and Finnish site investigation programmes with the text aiming to show the overall strategy for characterisation. It covers the approach to planning, including feasibility studies, and the need for plans to be driven by end-user needs. Site characterisation is divided into two parts: (i) site investigations, and (ii) interpretative modelling, with associated interaction and iteration. Lessons learned are provided. The text is currently under review by SKB and Posiva prior to wider circulation and is expected to contribute towards the supporting BIOPROTA publication.
- Supporting text on site analogues is at an earlier stage of drafting. It intends to inform on how analogue sites can be used in assessments as a substitute of space for time (e.g. to represent evolution of new land areas), as climate analogues for future conditions at a site, or as real sites to underpin generic assessments. It is anticipated that this material will contribute towards the supporting BIOPROTA publication.
- Text on identifying areas of interest will attempt to illustrate the process of identifying and understanding areas of interest in parallel with associated site characterisation and interpretative modelling. This understanding helps to provide data needed for assessments, such as flow paths from repositories to the surface system. It will include descriptions of approaches to identifying discharge areas and, from that, identification of areas of interest and delineation of biosphere objects. It is anticipated that this material will contribute towards the supporting BIOPROTA publication.
- A short appendix to the main report will be developed that summarises the PEGs/PEPs questionnaire and associated lessons learned. The appendix will not reproduce the responses in detail and, in so far as responses are referred to, the names of responders and/or associated organisations will be omitted unless explicitly agreed.

4. NEXT STEPS

4.1 REPORT FINALISATION

The draft report will be updated in light of the points raised during presentations and discussions, as summarised in Sections 2 and 3 of this report. A final draft will be distributed to BIOPROTA project sponsors and WG6 participants in by the end of September to allow final review and feedback prior to the October Technical Meeting.

A template for examples is to be developed and distributed in September. Organisations responsible for the assessments will be asked to provide:

- the way in which the examples should be summarised in the top-level table; and
- half page summaries highlighting specific aspects of note relating to the BIOMASS methodology.

The examples should be completed and returned by participants by the time of the Technical Meeting in October. All the examples provided should be published and readily available. Direct reproduction of text from existing reports (i.e. copy/paste) should be avoided to help ensure that copyright/plagiarism issues are not encountered during the IAEA publication process.

Text for an appendix summarising responses to the PEGs questionnaire is to be developed by the end of August and will be included as an appendix to the main report.

An acknowledgements section will be drafted by the WG6 chair, with support from the TST. This will be discussed and agreed during the October Technical Meeting.

4.2 MODARIA II WORK PROGRAMME PUBLICATIONS

Across MODARIA II as a whole, there is an intention to publish a special issue of the Journal of Radiological Protection to provide top-level papers describing the output from each working group. For WG6, this could summarise the methodology and draw on some examples. Care would be needed, however, to ensure that any figures or text do not lead to report publication issues. Publication as open access could help avoid such issues.

In addition to the overall methodology paper, several other papers have been identified that support the methodology such as the Mike Thorne/Ryk Klos paper on mathematical model development. Additional topics that could be developed into papers are to be considered by all participants for discussion during the October Technical Meeting, at which associated actions may be assigned.

4.3 MODARIA II FOLLOW-ON PROGRAMME

The MODARIA II programme concludes in 2019. Topics for a potential follow-on programme to MODARIA II were discussed. Topics for IAEA work programmes should be needs focussed and have the objective of improving assessments. The following topics were suggested.

- There is potential for looking at climate and landscape evolution on the timescale of a few millennia, gathering together projections of climate and sea-level change, ensuring consistency with the projections and guidance from the Inter-governmental Panel on Climate Change (IPCC).
- Experience of interaction and integration of site characterisation, site understanding and safety assessment could be drawn together to share experience of good practice and support those new to the topic.

- ☐ The BIOMASS methodology could be applied to legacy sites to investigate its broader application, potentially linking with site characterisation above.

4.4 SUMMARY OF ACTIONS

The following summarises the actions identified in the preceding text.

Action		Person(s) responsible	Timescale
1	Update report in the light of workshop discussions and distribute to sponsors and participants	TST	End of September 2019
2	Outline of supporting BIOPROTA publication	TST	By October TM
3	Template for examples to be distributed to sponsors and participants	TST	End of September 2019
4	Updated main-body text on PEGs	Lise Griffault/ Graham Smith	End of August 2019
5	Summary of PEG/PEP questionnaire exercise and lessons learned, for inclusion as an appendix	Lise Griffault/ Graham Smith	End of August 2019
6	Review report and provide suggestions supporting references throughout	All	End of September 2019
7	Specific review of Box 2 and accompanying text is invited	All	End of September 2019
8	Supporting detailed text on uncertainties and knowledge quality	Ari Ikonen	End of September 2019
9	Supporting detailed text on site characterisation	Tobias Lindborg/SKB	End of September 2019
10	Supporting detailed text on site analogues	Tobias Lindborg/SKB	End of September 2019
11	Supporting detailed text on the SKB/Posiva approach to identifying areas of interest	Tobias Lindborg/SKB	End of September 2019
12	Supporting detailed text summarising an alternative approach to identifying areas of interest	Ryk Klos/STUK/SSM	End of September 2019
13	Expressions of interest in suggested follow-on activities (see Section 4.3)	All	By October TM
14	Suggestions and justification for further potential collaborative follow-on activities	All	By October TM

APPENDIX A. MEETING PARTICIPANTS

The workshop was attended by the following participants.

Participant	Organisation
Alexander Diener	BfS, Germany
André Rübel	GRS, Germany
Andrej Guskov	IAEA, Austria
Ari Ikonen	EnviroCase, Finland
Björn Södderberg	SKB, Sweden
Branko Kontic	Josef Stefan Institute, Slovenia
Donghee Lee	KORAD, Korea
Emilie Aubonnet	Andra, France
Graham Smith	GMS Abingdon, UK (BIOPROTA TST)
Juergen Hansmann	ENSI, Switzerland
Karen Smith	RadEcol Consulting, UK (BIOPROTA TST)
Lauri Parviainen	Posiva, Finland
Lise Griffault	Andra, France
Maria Nordén	SSM, Sweden
Martin Steiner	BfS, Germany
Maryna Surkova	FANC, Belgium
Mike Thorne	Mike Thorne and Associates, UK (BIOPROTA TST)
Ray Kowe	RWM, UK
Reda Guerfi	STUK, Finland
Russell Walke	Quintessa, UK (BIOPROTA TST)
Ryk Klos	Aleksandria Sciences, UK
Shulan Xu	Xu Environmental Consulting, Sweden
Tobias Lindborg	SKB, Sweden
Ulrik Kautsky	SKB, Sweden