BIOPROTA

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

Report of the 2021 BIOPROTA Annual Meeting

27-29 September 2021

Version 2.0, Final
25 February 2022

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. Collaborative research within commonly focused projects is intended to make efficient use of skills and resources, to draw on international experience 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 primary 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 the best sources of information available to justify modelling assumptions required within long-term safety assessments.

Particular emphasis is placed on key data for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge or release to the surface environment.

The programme of activities is driven by needs identified from previous and on-going assessment projects. Where common needs are identified amongst BIOPROTA members, a collaborative effort can be applied to finding solutions.

This report describes presentations and discussions held during the 2021 BIOPROTA annual meeting. As a result of the ongoing COVID-19 pandemic, the meeting was held as a series of web-hosted sessions via Microsoft Teams, from 27 to 29 September 2021. Technical inputs were provided by a wide range of organisations via presentations and discussions, as described in this report.

The report is presented as working material for information. The content may not be taken to represent the official position of the organisations involved. All material is made available entirely at the user's risk.

Version History

Version 1.0: Draft meeting report prepared by Karen Smith (RadEcol Consulting Ltd) based on participant contributions and reviewed by Russell Walke (Quintessa Ltd) prior to distribution to meeting participants on 24 January 2022.

Version 2.0: Final meeting report prepared by Karen Smith (RadEcol Consulting Ltd), taking into account participant comments on version 1.0. Distributed to meeting participants and forum members 25 February 2022.

CONTENTS

1. INTRODUCTION

The annual BIOPROTA meeting is designed to provide a forum for continuing exchange of information and discussion on topics of special interest in national programmes, and an opportunity to update participants on progress on the various projects and activities supported through BIOPROTA. It also aims at providing an opportunity to discuss topical issues, with the intention that, where there is sufficient interest among member organisations, discussions could lead to the development of future collaborative research and assessment work programmes.

In light of the ongoing Covid-19 pandemic, the 2021 annual BIOPROTA meeting was organised as a series of 3-hour web-hosted sessions over 3 days that focussed on updates on individual programs and research from member organisations, progress with ongoing BIOPROTA work programmes and discussion of common themes and ideas for future work programmes. This report provides an overview of the presentations and discussions throughout the meeting.

1.1 OVERVIEW OF THE BIOPROTA FORUM

The international BIOPROTA forum was set up in 2002 with the following objectives.

- 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.
- To make available the best sources of information to justify modelling assumptions made within long-term safety assessments, noting that there is strength in being consistent across different programs where assessment contexts are similar.

The members are the heart of the forum with membership aimed at national authorities, agencies and other organisations, including technical support organisations and independent research institutions, with shared interests related to achieving safe and acceptable radioactive waste management. There are currently two grades of membership. Full members pay a membership fee that is used to support the role of the technical secretariat which provides technical and administrative support to the forum and coordination of meetings. Full members have a seat on the Sponsoring Committee that decides on the direction of the forum and its work programme. Academic members do not pay a membership fee, but do not form part of the Sponsoring Committee. The Sponsoring Committee is headed by a chairperson who is elected each year during the annual BIOPROTA meeting. The current chairperson is Alex Diener (BfS). The structure of the forum is illustrated in Figure 1.

An annual meeting of the forum is held to report on progress in the biosphere programs of member organisations and to provide an opportunity for discussion around topical issues and to discuss ideas for projects to support the resolution of shared assessment issues and uncertainties. Topical workshops are also held on particular issues of common interest that provide an opportunity for organisations to discuss topics in depth and to which external expertise may be invited. Presentations and discussions are recorded in topical workshop reports and can, where there is sufficient interest and support among forum members, lead to technical projects.

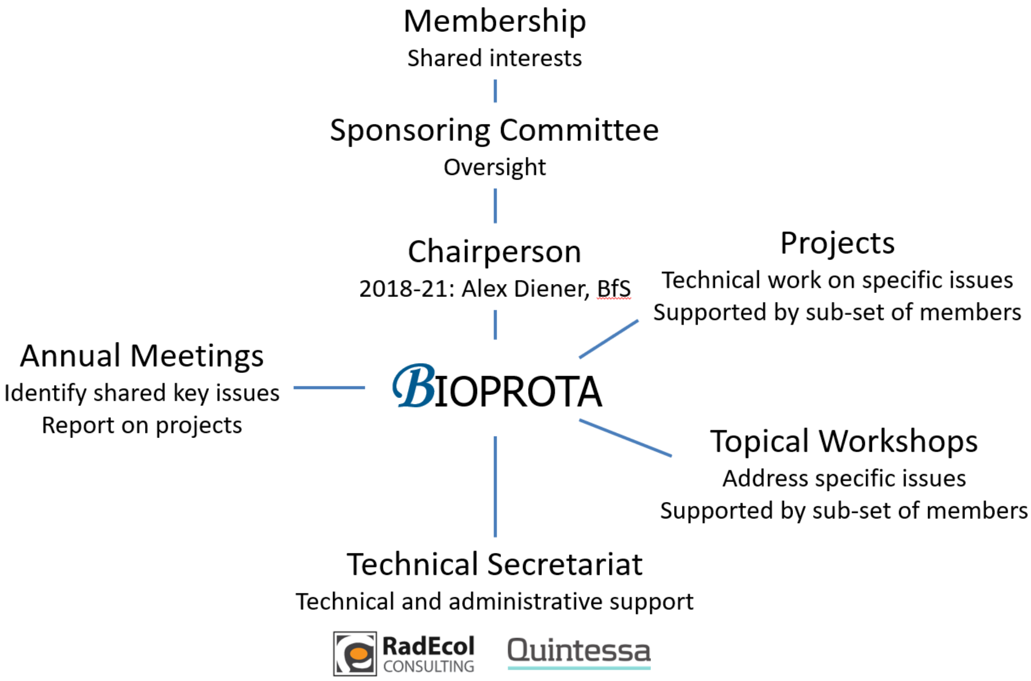

Figure 1. Structure of the BIOPROTA forum.

Proposals for collaborative projects or workshops are welcome from members of the forum at any time and are distributed amongst members for consideration. The proposals detail the planned scope of work, deliverables and propose a technical support team to deliver the works and full project costs. Member organisations are then invited to consider supporting the projects financially and/or technically. If successful, sponsors are invited to form a project steering group to oversee the project and approve project deliverables prior to wider distribution. Results of the project are presented and discussed during the annual BIOPROTA meetings and final project reports are, where approved by sponsors, made publicly available on the BIOPROTA website.

In 2020 there were 23 full member organisations and 4 academic members with membership being fairly consistent over recent years. The sponsoring and academic members in 2020, that have been invited to continue membership in 2021, are as follows:

Full member organisations

- Andra, France
- ARAO, Slovenia
- BfS, Germany
- DSA, Norway
- EDF, France
- ENSI, Switzerland
- EPA, USA
- FANC, Belgium
- IRSN, France
- JANUS, Japan
- KAERI, Korea
- KORAD, Korea
- LLWR, UK
- Nagra, Switzerland
- NUMO, Japan
- NWMO, Canada
- Posiva, Finland
- RWM, UK
- SCK·CEN, Belgium
- SKB, Sweden
- SSM, Sweden
- SURAO, Czech Republic
- UJV, Czech Republic

Academic members

- Oregon State University (OSU), USA
- University of Life Sciences (NMBU), Norway

- Clemson University, USA
- Royal Institute of Technology (KTH), Sweden

In addition, the University of Eastern Finland (UEF) has expressed interest in joining as an academic member and were therefore invited to present in support of their membership during the annual meeting.

1.2 PARTICIPATION

The organisation of the 2021 annual meeting as a series of web-hosted meetings allowed for greater participation from member organisations than would be feasible for a face-to-face meeting. The meeting was attended by 47 participants from 14 countries, representing a range of operators, regulators, researchers and technical support organisations. Participants are listed in Appendix A, along with affiliations.

1.3 REPORT STRUCTURE

Section 2 of this report summarises the presentations from meeting participants on progress and perspectives from member organisations. Section 3 provides an overview of the presentation by UEF in support of academic membership, Section 4 summarises progress with ongoing work programmes and Section 5 details the presentations and discussions around potential topics for further collaboration and dissemination opportunities. Feedback from the sponsoring committee and forum arrangements for 2022 are detailed in Section 6.

2. PROGRESS AND PERSPECTIVES FROM MEMBER ORGANISATIONS

Presentations from meeting participants on their biosphere programmes, issues and uncertainties are summarised in this section, including related discussions.

2.1 THE EFFECT OF NON-RADIOLOGICAL POLLUTANTS ON NON-HUMAN BIOTA

Ray Kowe (RWM) presented.

Radioactive wastes that are consigned to a geological disposal facility will also contain other, non-radiological, pollutants. Non-radiological pollutants will also be present in the backfill and the structural components of the facility. The safety case developed for a geological disposal facility will need to demonstrate that the impact of radioactive wastes and of non-radiological pollutants on humans and the environment meets regulatory requirements. These requirements include the protection of non-human biota. Therefore, RWM is undertaking a programme of work to identify the non-radiological pollutants of potential importance for a GDF, and to quantify the amount of these pollutants that will be present in the GDF. Work is also underway to investigate the behaviour and impact of these non-radiological pollutants in the environment.

The purpose of the work is to:

- examine relevant UK and EU legislation surrounding the fate of non-radiological (chemical) pollutants in the environment and their impact on wildlife; and
- outline a simple analytical framework for a screening-level risk assessment of the potential effects of environmental contamination on common species (using basic toxicological criteria in aquatic and terrestrial media).

The work considers a small subset of non-radiological pollutants representative of different chemical groups and for exposure pathways such as direct contact (particularly intake) but also via secondary poisoning. Secondary poisoning occurs in organisms at higher trophic levels of the food web in both aquatic and terrestrial environments as a result of ingestion of organisms from lower trophic levels that contain accumulated pollutants.

Simplistic food chains considered are, for freshwater:

water → aquatic organisms → fish (predator)

and for terrestrial ecosystems:

soil → earthworm → worm-eating birds or mammals (predator).

Humans are considered in the predator category through their consumption of fish.

A simple methodology based on bioaccumulation is proposed as an approach to assess the potential impact of toxic pollutants on terrestrial wildlife. It could function as the first screening step in a tiered ecological risk assessment.

RWM will engage with the UK regulators as to the applicability and validity of this proposed approach.

Discussion

It was noted that SKB previously looked at sub-surface fauna (stygofauna) by studying areas outside sites being considered for geological disposal. Stygofauna were found to inhabit specific geologies and, therefore, if those geologies were not present at proposed sites, then protection of stygofauna would not be an issue. The identification of the boundary between volumes of rock where biota exist and where they do not is a matter to consider.

2.2 UPDATE ON BELGIUM'S NATIONAL PROGRAMME

Maryna Surkova (FANC) presented.

There are four nuclear sites in Belgium: Doel, Mol·Dessel, Fleurus and Tihange. The principal activities generating spent nuclear fuel (SNF) and radioactive wastes include fuel fabrication at Dessel, which ceased operations in 2015 and is now toward the end of the decommissioning stage, and electricity production at Doel and Tihange that together comprise seven reactors. From 2022, the reactors will begin to be phased out and dismantling activities will begin. There are also four research reactors at Mol and radioisotope production at Fleurus.

Current nuclear and waste liabilities in Belgium and practices for addressing them are as follows.

- Spent nuclear fuel: wet and dry storage on-site at nuclear power plants (NPP) and storage or reprocessing of SNF from research reactors. The long-term policy for SNF is still to be defined but will involve either direct disposal of SNF or disposal of waste arising from reprocessing. Geological disposal is still to be confirmed by a Government policy decision.

- Nuclear fuel cycle waste: All short-lived low and intermediate level wastes (SL-LILW) and long-lived low and intermediate level wastes (LL-LILW) are currently stored at a centralised storage facility at the Belgoprocess site, and high-level wastes (HLW) are transferred to the Belgian waste management organisation ONDRAF/NIRAS. The long-term management policy for SL-LILW is near surface disposal. Geological disposal of LL-ILW and HLW is still to be confirmed by Government policy decision.

- Non-power reactors waste: SL-LILW, LL-LILW and HLW are treated the same as for nuclear fuel cycle wastes. Radium wastes are currently stored at Umicore/Olen and a long-term management policy is still to be defined.

- Decommissioning liabilities: The long-term management policy is the responsibility of the operator and decommissioning plans are approved by ONDRAF/NIRAS.

- Disused sealed sources: These are returned to suppliers, sent for decay storage or transferred to ONDRAF/NIRAS.

The regulatory framework in Belgium has improved in recent years. One of the most important improvements was a 2018 Royal Decree on the safety of facilities for the storage of SNF and radioactive waste that calls for site inspections and overall improvements to nuclear safety. There have also been proposals relating to radioactive waste disposal facilities relating to licensing and safety requirements that are fully compliant with WENRA[a] reference levels.

Another recent development has been the granting of a licence in 2020 by Royal Decree for the construction of an on-site SNF interim storage facility at the NPP site in Tihange. In Belgium, SNF is not declared as waste, hence it is subject to on-site storage with the decision having been made for dry storage. It is intended that the facility will be operational by 2023. The licensing process for a SNF storage facility at Doel is ongoing, with the objective of having an operational storage building by 2025.

Non-conform wastes from NPPs have been an issue in Belgium. A routine inspection of conditioned and stored LLW at Belgoprocess in 2012 identified a yellow gel-like material on the outer surface of a waste package. Opening of the package revealed that the substance was precent on the whole surface of the concrete matrix within and similar observations were made on other packages containing the same type of waste. As such, ONDRAF/NIRAS broadened inspections and research and development activities identified an alkali-silica reaction (ASR) had caused the phenomenon. A roadmap for dealing with the issue was developed by ONDRAF/NIRAS that covers seven themes:

- major inspection program;
- research and development;
- operational safety of interim storage;
- long term safety, i.e., impact on final disposal;
- impact on the Waste Acceptance System;
- impact on treatment and conditioning processes; and
- financial aspects.

Four key aspects are being considered with respect to the long-term management of non-conforming drums. Drums of waste where ASR is not present can be consigned to surface disposal. For ASR affected drums, surface disposal may be possible with a modified design if further ASR can be excluded, or it may be possible to consign to either surface or geological disposal if it can be demonstrated that the gel will not have a negative impact on barriers. Alternatively, it may be necessary to recondition the ASR affected waste to a stable end-product for disposal.

Other recent developments in Belgium include:

- inspection program on nuclear waste management;
- progress on decommissioning programmes;
- finalisation of the decommissioning of the Belgonucleaire MOX fuel fabrication facility;
- progress in the decommissioning at Belgoprocess site;

[a] Western European Nuclear Regulators' Association (WENRA), https://www.wenra.eu/.

- progress in the decommissioning of FBFC international;
- progress in the decommissioning of the BR3 of the Belgian Nuclear Research Centre, SCK·CEN;
- progress in the decommissioning of the facilities of the former Best Medical Belgium (ONSF) site; and
- licensing of the surface disposal facility in Dessel.

In terms of policies and practices, a national programme of the management of SNF and radioactive waste has been established in accordance with Council Directive 2011/70/Euratom of 19 July 2011 establishing a community framework for the responsible and safe management of SNF and radioactive waste. The national programme describes the status of management of SNF and radioactive waste at the end of 2014. There have been no revisions or updates to the programme since this time. The policy for very short-lived waste is for decay and clearance and short- and medium-term management strategies are in place for SL-LILW and SNF.

During the 2020 annual BIOPROTA meeting, a short presentation was provided concerning FANC-Bel V advice on geological disposal. ONDRAF/NIRAS has proposed a national policy to develop geological disposal for SNF, HLW, other intermediate-level radioactive waste from reprocessing and decommissioning and for other radioactive waste for which no management solutions exist (e.g. radium). FANC was in favour of the proposed principle, but how, where and when the repository would be constructed is not yet under discussion. In advice given by FANC on the proposed principle, reasons why geological disposal was considered the safest solution were given:

- geological disposal is the safest solution with regard to the current scientific knowledge;
- waste is confined and isolated from the mankind, meeting two long-term safety functions of confinement (contain and limit escape of radionuclides) and isolation (separation of the waste from the biosphere);
- risks associated with contextual uncertainties are minimised (such as wars, climate change and lack of financial resources);
- passive safety: no human intervention is required anymore after closure; and
- national policy is necessary and urgent to start a “step-by-step” decision-making process.

SITEX was also presented during the 2020 annual meeting. This is a European network of experts on radioactive waste management that involves technical support organisations, regulators and civil society that aims to ensure public involvement in the decision-making process. Within the SITEX network, a path evaluation process (PEP) game has been developed that allows structured discussion between individuals about the complexity and challenges associated with safe and long-term radioactive waste management. The game can be used as a tool for interacting constructively with civil society. The game was used at an event at the University of Liege in Belgium attended by 80 engineer and political scientist students plus professors from the research units. The students felt the experience of this type of activity was positive and, whilst debate is not always necessary, being transparent, providing information and giving time for discussions, without pushing opinions were valued. Results from the event are available from the following links:

- https://www.uee.uliege.be/cms/c_6516625/fr/un-serious-game-pourdiscuter-des-dechets-radioactifs-a-l-uliege-une-grande-premiere-enbelgique

- https://www.4sonline.org/meeting/

A Belgian-issues focussed board game is now being considered for development by the regulatory bodies.

Discussion

Geological disposal of problematic wastes was noted as being a topic of particular interest and could form the basis for a topical session during the 2022 annual BIOPROTA meeting.

2.3 RECENT ACTIVITIES AT BFS

Alexander Diener (BfS) presented.

One of the recent activities at BfS has been modelling of upward infiltration experiments with mixed radionuclide solution. Drivers behind this work are that rising groundwater in valley bottoms is a common phenomenon and, if the rising groundwater is contaminated with radionuclides, they could be available for plants. As such, Kd's for lower soil layers are of interest. Column experiments were therefore set up to quantify the upward migration of nine long-lived radionuclides in two typical German agricultural soils in order to evaluate the retardation of the radionuclides through the soil layers. Kd values were measured in different soil layers. A model that couples thermodynamic speciation calculations (PHREEQC) with water flow calculations (HYDRUS-1D) was then used to provide insight into the reactions taking place.

The soil columns used in the experiments were 43 cm high and 30 cm diameter. The reference soils were Refesol 2 (sand) and Refesol 4 (loam). Contaminated water entered the soil columns from the bottom with capillary forces causing the water to rise through the column. The radionuclides used in the experiments were Ni-63, Se-75, I-129, Cs-134, Ra-226, Np-237, Pu-238, U-238 and Am-241. The experiments ended when no further water movement was detected, at which point soils were extracted and the lower three layers of 3 cm thickness were analysed, along with pore water.

In modelling the reactions taking place, illite was used as a proxy for the clay minerals present in the soils with sorption of illite being described in terms of five different sorption sites. For example, sorption on the ferrihydrite component of soil was modelled using the model of Dzombak & Morel (1990)[b], which considers complexation reactions for two types of binding sites and the sorption of elements on organic matter was considered by using Tipping (2002)[c] Model VII (2002), which considers two classes of specific sorption sites for humic and vulvic acids.

Results show that, with the exception of I-129 and U-238, radionuclides had short transport distances, with the greatest transport being seen in the lowest layer, which was also associated with the highest Kd. In contrast, I-129 was very mobile, whereas U-238 was found to be difficult to analyse due to high background activities in soils.

The model applied was satisfactory in modelling the upward infiltration of water through the soil columns and for Cs-134, U-238, Ra-226 and Se-75, the experimental Kds were in good agreement with the

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[b] Dzombak, D.A. and Morel, F.M.M. (1990), Surface Complexation Modeling: Hydrous Ferric Oxide, John Wiley & Sons, New York.

[c] Tipping, E. (2002), Cation Binding by Humic Substances, Cambridge University Press, Cambridge.

model results. However, for I-129, Np-237 and Ni-63, thermodynamic constants need to be reviewed and for Ra-226, Pu-238 and Am-241, the experimental results indicate that precipitation is an important process that needs to be included in the model. Results of the study will be published.

A second recent activity at BfS has been a study of intake rates across the German population, which has been undertaken in cooperation with GRS. The intake rates are needed in order to calculate the ingestion of radionuclides in dose calculations associated with emissions from facilities and waste repositories. The current data used in assessments are around 20 years old and therefore require updating. Ten different food groups are considered of which two (drinking water, mother's milk) are assumed to be 100% local consumption in assessments. For the other groups, 50% local consumption is assumed. Six different age groups are considered (<1 year, 1 – 2 years, 2 – 7 years, 7 – 12 years, 12 – 17 years and over 17 years).

The first part of the study (investigating studies from 2000 to present and obtaining data from the study owners) has been completed. The next step will be to transform the data by reorganising into unprocessed food groups and converting these data into a table of food groups required by the Radiation Protection Act.

In terms of the regulation for dose calculations after potential releases of radionuclides from a HLW repository, the current situation in Germany is that Step 1 out of 3 of the site selection search has been completed, which has involved desk-based map studies of hydrogeological criteria to select possible sub-areas for a repository location. As a result, 90 sub-areas covering 54% of the area of Germany are still considered. These comprise clay rock, salt rock and crystalline rock areas. Step 2 of the process will then involve surface exploration and subsurface drilling within these areas to narrow down the search. Step 3 will then involve further subsurface exploration and proposal of a site.

A comprehensive draft administrative regulation for calculating effective doses to the public from the HLW repository has been developed. The regulation contains 82 pages that specify radionuclide transport in the host rock, biosphere modelling and dose calculations required for Steps 2 and 3 of the site selection process. For the dose calculations, the lifetime average additional effective dose for a representative person is calculated. The calculations are required to consider the use of contaminated groundwater or surface water for drinking water, irrigation water and water for livestock and assume unfavourable conditions with respect to food production and habitation. Gas transport from the geosphere to the atmosphere also needs to be considered and there is a requirement to use site-specific information, such as useable aquifers, where available and if valid for the period of time and any assumptions must be justified. Climate change and transitions are also required to be taken into account, including impacts of anthropogenic emissions on climate change, and should be consistent between the geosphere and biosphere models. Compatibility between climate conditions and farming assumptions should be plausible and morphological changes to the surface driven by climate change should be considered.

For radionuclide transport and environmental contamination, model input data for the geosphere-biosphere interface should include the flow rate of groundwater and concentrations of radionuclides, input rates for gaseous radionuclides and calculation of contamination in near-ground air and uptake to plants through photosynthesis, and the concentration of dissolved salts in the aquifer. Pathways that need to be taken into consideration within the biosphere include contamination of rivers and lakes, including riverside sediments, and contamination of soils and plants as a result of irrigation, assuming irrigation by demand, which can be based on monthly data on air temperature, precipitation and relative air moisture, or a constant rate over 6 months of the year can be assumed. Contamination of plants due to rising groundwater should also be considered. Exposure pathways for the representative person then include exposure from soil and riverside sediment gamma irradiation, inhalation of gaseous radionuclides and resuspended soil particles and the ingestion of food and soil particles. The present kind of living conditions and habits, including sustainable agricultural practices, are to be assumed for the whole period of the safety analysis.

The draft regulation has been reviewed by stakeholders and feedback has been implemented, but public feedback on the regulation is still pending.

Discussion

Usable aquifers will be determined on a site-specific basis by the operator with arguments being put forward with justification on which aquifers can and cannot be considered usable. This will take into account the local hydrogeology to determine whether or not water can be extracted.

It was noted in response to the soil column experiments that biological processes within soils can be important in influencing radionuclide behaviour. For example, soil organics can aid transport and sharp changes in redox conditions can result in the precipitation of radionuclides.

On the studies of dietary intakes, it will be interesting to consider how diet has changed within a lifetime. However, it will be important to recognise that the amount of information on current habits will be considerably more comprehensive than previous studies. For example, studies have been ongoing since 1995 on children and young adult consumption habits such that there is now a 30-year trend of intake rates. Regional differences are also being investigated.

2.4 POSIVA'S BIOSPHERE PRORAMME – CURRENT STATE

Lauri Parviainen (Posiva) presented.

By the end of 2021 Posiva will submit an operational license application for the Olkiluoto repository for SNF. The application is progressing within a tight and challenging schedule. Alongside activities associated with the license application, construction activities are ongoing and these are progressing as planned with the encapsulation plant, which includes a handling room for SNF to be loaded into copper canisters, due to be completed in 2022.

The models being applied in the 'TURVA-2020' safety case are similar to those applied for the 2012 construction license application. A terrain and ecosystem development model (TESM) looks at how the site could look in the future as new land areas emerge with post-glacial land uplift and considering different climate assumptions. A surface and near-surface hydrological model (SHYD) then uses TESM results, along with climate data, to model groundwater and radionuclide transport to and within the surface environment. A detailed landscape model (LSM) is then applied to model radionuclide transport and perform both deterministic and probabilistic dose calculations within a 10,000-year assessment timeframe. The LSM also performs dose rate calculations for non-human biota. Additional requirements from the regulator following the 2012 assessment were for some dose calculations to be performed for longer timeframes (up to 1 million years). As such, simplified biosphere and landscape dose models have been developed and applied to these longer timeframes.

The TESM model has been applied for two climate variants – RCP 4.5 (global warming) and RCP 8.5 (extended global warming). In the extended global warming scenario, Olkiluoto will be submerged after 500 years. This will have the effect of slowing geosphere transport of radionuclides and, where radionuclides are released, these will be diluted considerably due to release to the Baltic Sea. In later timeframes, the landscape in the extended global warming scenario is similar to that in the global warming scenario. Some differences in croplands occur but the differences are small.

The SHYD also gives boundary conditions for groundwater flow modelling and is applied to two glacial cycles over an assessment time window of up to 120,000 years. Differences are observed in rates of precipitation during temperate periods, but the consequences in terms of dose need further evaluation.

The LSM consists of multiple biosphere objects, the properties of which are derived from the TESM results. Each biosphere object is defined in terms of the biotope(s) present and soil type and layer thicknesses. The biosphere objects in release locations tend to be small but increase in size with distance from release areas as they are less relevant to dose. For the simplified biosphere model, the Olkiluoto site is presented as a 100 m by 100 m grid with each grid cell being an independent biotope with soil properties from the TESM. The model can be applied to look at the effect of release location and to look at different calculation cases, such as multiple canister failures with different release locations to identify where consequences for dose calculations may be greatest. Studies indicated that release locations occur either to the north or south of the island and mostly occur within a relatively small area.

In the 2012 assessment, the reference case was based on a pinhole release from a canister. In the TURVA-2020 assessment, the base case is that all SNF canisters remain intact for the whole detailed dose assessment timeframe, but releases from the LILW repository can occur as the barrier system associated with this repository will not prevent releases from occurring. Results for this base case are between 100 and 1,000 times higher in the simplified landscape dose model (SLDM) than the more detailed LSM.

Several 'what-if' calculation cases are considered for the SNF repository, including a scenario whereby one canister fails within 300 years post-closure. Again, doses are around 100 times greater for the SLDM compared to the LSM. This is largely due to the release object in the LSM being around 20 hectares compared to 1 hectare in the SLDM. Soil thickness is also shallower in the SLDM which also affects dose calculations. A further longer-term calculation case (GC-C2) considers chemical erosion of the buffer around canisters, resulting in the corrosion of over 100 canisters. In this case, results of the SLDM exceed the dose limit of 0.1 mSv/y, set by the regulator for the first 10,000 years, by 10 times at around 590,000 AP. The LSM averages dose for the most exposed 20 persons whereas the SLDM presents results for the single most exposed person and includes many conservatisms, such as soil thickness and biosphere object area. Results are, therefore, very conservative.

Initial results indicate that release location has some effect on calculated doses. The presence of lakes, in particular, is noted with C-14 being important for dose, particularly for releases early in the assessment time window. Soil thickness results in large differences between the different dose models. The milk exposure pathway is also a major contributor to calculated doses, resulting largely from the high concentration ratio (CR) for Cl-36 in forage. The CR for Mo-93 to forage is also over 1. After milk ingestion, ingestion of water from a well in the overburden is the next major dose contributor (noting that a drilled well was still to be analysed at the time of the meeting). Ingestion of fish from small lakes was noted as important, due to C-14.

The key radionuclides for the SNF repository in early (10,000 years post-closure) what-if cases are Cl-36, I-129, Mo-93, Ag-108m and C-14. On longer timescales, Ni-59 and Ra-226 are also important. A radon model has also been applied to consider radon exposures in houses. Doses remain around 10 to 100 times lower than for other exposure pathways.

At the time of presenting, there remained around three months to complete the assessments and reporting before the submission deadline of 31 December 2021. During this time, alternative landscape evolutions were to be studied and model assumptions were to be investigated. An extra-long LSM case was also to be run to cover the period up to the next glaciation (380,000 years). Probabilistic calculations and non-human biota dose rate calculations were also to be performed.

Discussion

In the SLDM, releases are directed to biosphere objects that consist of properties, such as soil thickness, averaged across the landscape for the type of biotope assumed within the object of interest, based on output from the TESM. In the case of the LSM, the properties from the TESM for the actual release location are applied, which gives rise to the differences in soil thickness for release locations between the models.

2.5 DYNAMIC MODELLING OF IODINE CYCLING IN FORESTED ENVIRONMENTS

Yves Thiry (Andra) and Taku Tanaka (EdF) presented.

A dynamic model has been developed for iodine in forests, based largely on a previous model for chlorine in forests. The model development has been undertaken by a number of partners in France, including Andra, EdF and IRSN, within the frame of a national project.

The fate of iodine in the environment is of interest for a number of reasons. Stable iodine (I-127) is a deficient micronutrient in numerous regions. I-131 is a short-lived radiotoxic radionuclide that has been important in accidental releases, including Fukushima. I-129 is a radionuclide of potential interest in terms of radiological impact from radioactive wastes and is also present in the environment as a result of natural sources and anthropogenic releases. Recent publications (e.g. Cuevas et al., 2018[d] and Aldahan et al., 2007[e]) demonstrate that there continues to be interest in the global terrestrial iodine budget, but that inventories and residence times are unclear and questioned. For example, Aldehan et al. (2007) identifies difficulties in linking releases, recycling in the biosphere and export to aquatic systems for I-129, giving rise to an important scientific question of what are the sources of I-129? Furthermore, Cuevas et al. (2018) noted that I-127 in the northern atmosphere has tripled over a 60-year period.

Naturally occurring I-129 is produced by the spontaneous fission of uranium in the lithosphere and by cosmic-ray-induced spallation of xenon in the atmosphere. However, anthropogenic sources dominate, with around 95% of anthropogenic releases being associated with SNF reprocessing at Sellafield in the UK and La Hague in France since the 1950s. A further 3% is associated with past nuclear weapons testing and less than 0.1% results from the Chernobyl accident with the contribution from Fukushima being considerably lower. These anthropogenic sources affect the I-129/I-127 isotopic ratio with current ratios being between 2 and 8 orders of magnitude higher than the natural isotopic ratio. The ratio could change a lot more in the future considering the majority of SNF has not yet been reprocessed.

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[d] Cuevas et al. (2018). Rapid increase in atmospheric iodine levels in the North Atlantic since the mid-20th century. Nature Communications 9: 1452.

[e] Aldahan et al. (2007). I-129 anthropogenic budget: major sources and sinks. Applied Geochemistry 22(3): 606-618.

The biogeochemical iodine cycle involves a complex interplay between solid, aqueous and gas phases, as discussed in Neeway et al. (2019)[f], with several processes controlling the fate and transport of different isotopes. Key influential factors include the concentration of iodine, redox potential, pH, presence of organic matter, redox-sensitive elements in minerals such as iron and manganese, and microbial activity. It is well known that fungi and bacteria play an important role in the iodine redox cycle and interaction with biological matter in soils, which is an important variable controlling speciation and persistence in surface soils.

In order to deal with the complexity of the iodine cycle, it was postulated that complex behaviour in soil could be represented by the coexistence of labile and non-labile forms in both the forest floor and underlying soils, with forests being the focus due to more stabilised iodine cycles being expected. Coefficients for the transformation of iodine in soil and to distinguish between labile and non-labile forms have been proposed and it was hypothesised that non-labile forms would accumulate in organic matter. The formula applied in the model were used previously for a model on chlorine in forests and followed a similar approach. Data supporting the model were very important and stock and flux measurements from a series of monitoring sites across France are used, with model data being based on several published sources.

The atmosphere provides input to the model and is also a sink for volatilisation. A high reactivity of iodine on the surface of vegetation within the forest canopy was assumed and, in the forest floor, both labile and non-labile forms are distinguished and roots specifically accounted for.

In order to optimise the concept, a tool was developed that integrated available knowledge. The temporal distribution and accumulation of iodine in forest ecosystems was then simulated for atmospheric deposition. The model, which was built in the ECOLEGO software, used a series of linear differential equations with constant transfer coefficients. Altogether there are nine compartments (atmosphere, tree surface, internal tree, roots, forest floor, soil and deep soil with the forest floor and soils being sub-divided into labile and non-labile compartments) and 18 transfers.

Evaluation of the model has been performed by testing different scenarios involving I-127 and/or I-129 atmospheric deposition and soil conditions. The model has also been tested against independent data sets from the RENECOFOR network and Andra-Ope site and a validation exercise performed using an interesting dataset from Lower Saxony in Germany that included both I-127 and I-129 data. A pulse I-129 release from Chernobyl was also modelled. For each scenario, atmospheric deposition from field observations were used as model input with observed iodine inventories in soil compartments being used to compare against model predictions.

Initial scenario runs considered only wet deposition as input, resulting in slight underestimation of soil concentrations. When dry deposition was also considered, the correlations were improved. Overall, there was good agreement between the model and measured data, with model results corroborating the view that soil acts as a sink for iodine. There were a few exceptions where the model did not perform so well (a spruce forest, a site developing on carbonate shales and another on calcareous rocks). For these three examples, even the addition of dry deposition failed to explain the observations. At two sites, weathering of carbonaceous rock was thought to interfere with the loading of iodine in soils. This

[f] Neeway et al. (2019). A review of the behavior of radioiodine in the subsurface at two DOE sites. Science of the Total Environment 691: 466-475.

is a known phenomenon, but the model allowed quantification of the extent of influence of this process on iodine budgets (between 30 and 80%).

For the Lower Saxony I-127 and I-129 deposition case, the simulation was run for 5,000 years for I-127 and between 1950 and 1999 for I-129. Results were in good agreement for I-129 and there was a modest overestimate for I-127. For both isotopes, inclusion of dry deposition improved the correlations.

A mass balance for iodine in forests was reconstructed based on steady state partitioning in a generic scenario. The results were interesting in that low residence times in vegetation and the forest floor were calculated. A low residence time (<90 years) was also calculated for the labile pool in soils with the residence time of the non-labile pool being a factor of 10 higher. In terms of fluxes, volatilisation was more important than drainage, except where calcareous rock was present.

Initial model simulations for the Chernobyl scenario were not in good agreement with measured data for forest floor and soils. Chernobyl soils are very sandy and the climate conditions also differ from those in France (average precipitation is much lower for Chernobyl) and adjustments were therefore made (e.g. to leaching parameters). Following adjustments, the model had much better agreement with observations.

The studies have shown that the major source of iodine in forests is the atmosphere with dry deposition being important except where limestone weathering can impair contributions. However, the mobility and distribution of I-129 at one site cannot be extrapolated from another if historical inputs have differed. The non-labile pool in soils is the ultimate reservoir for iodine with root uptake having a negligible influence. Based on the findings, it is proposed that two cycles operate over different timescales. The non-labile pool equates to around 20% of iodine deposits and has a mean residence time in soil of around 900 years whereas the labile pool equates to 80% of deposits, with a mean residence time of 90 years. The main efflux of iodine from the system is due to volatilisation, which dominates over drainage. Finally, results indicate that it can take decades to centuries for the different iodine pools to stabilise, which is why isotopic disequilibrium is commonly observed in field studies.

2.6 LOW AND INTERMEDIATE LEVEL WASTE (LILW) REPOSITORY IN SLOVENIA

Špela Mechora (ARAO) presented.

ARAO is the organisation in Slovenia responsible for the disposal of radioactive waste. Countries with nuclear programs also need to have radioactive waste disposal programs and it is good to have at the outset a good knowledge of the waste inventory, the financial status for the program, the national and international framework for radioactive waste disposal and the preferences of major interested parties.

Several locations and disposal concepts were considered for LILW. The selected disposal concept in Slovenia is a near-surface silo, excavated from the surface, with a final design having been finalised in 2015. The disposal silo will be accompanied by technical and administrative buildings. Wastes to be disposed include operational and decommissioning wastes from nuclear power plant and wastes generated in medicine, industry and research that are currently in interim storage. The waste inventory also includes wastes generated during the operation of the repository and the decommissioning of buildings at the repository site. The silo capacity is 990 containers, disposed of in 10 layers of 99 units. The capacity and design are intended to take half of operational and decommissioning wastes from nuclear power plant up to 2043 and other LILW from other Slovenian generators.

The design concept is based on a multi-barrier system where individual repository components perform multiple safety functions. The first barrier is a metal drum for wastes that are then placed in concrete containers (barrier two). Concrete containers are then emplaced within the concrete silo (barrier three) that is constructed in silt (barrier four). The silo will be located below the groundwater level to prevent flooding after closure (Figure 2).

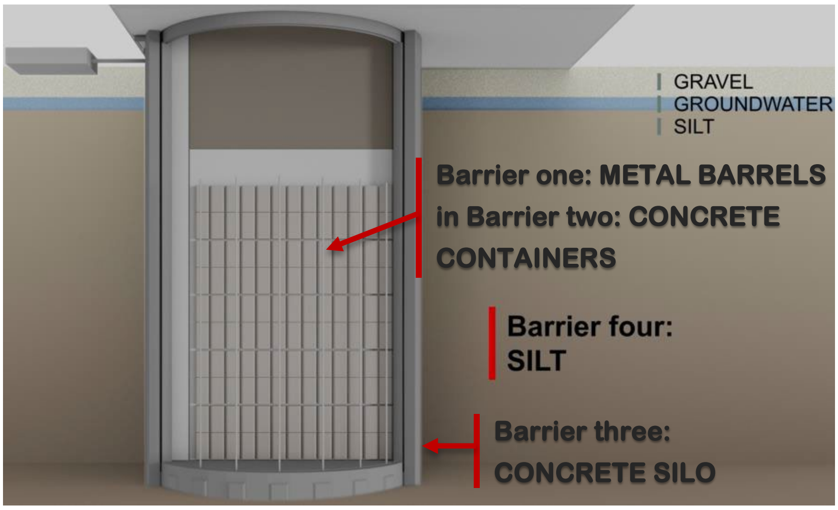

Figure 2. Multi-barrier disposal concept illustrating concrete containers within the below-ground silo constructed in silt.

The Silo provides various functions, including durable storage space, a biological shield, and an engineered barrier that limits water ingress and the release of contamination to the environment. Once wastes have been emplaced within the silo, further infill will be added to provide additional protection.

Concrete containers will be N2d-type that are designed to take metal waste drums, TTC or both, up to a maximum weight of 40 tonnes. The containers provide structural stability and physical and chemical retention of radionuclides. They also protect against human intrusion.

A single disposal silo will be constructed, along with all technological and other facilities and associated infrastructure. The construction phase should take 3 years to complete. Following construction there will be a trial operation period of up to 2 years, followed by an initial operational deposition phase of around 3 years. This will be followed by a standby phase where no disposal or other more extensive works will occur. Around 2049 the operational deposition phase is expected to recommence for the disposal of remaining operational and decommissioning wastes. Closure of the silo is proposed to occur between 2058 and 2059 with closure being followed by a 300-year long-term control period, comprising of a 50-year active control period with active monitoring followed by 250 years of passive long-term monitoring. The site will subsequently be made available for unlimited use.

The siting process began in 2004 and a site was selected 5 years later. A Decree on the detailed plan and disposal concept was also approved in 2009. The first iteration of the safety assessment was submitted in 2011 with a feasibility study being approved and final site investigations being completed in 2014. The final design was completed in 2015 and, based on this, a revised safety assessment was performed between 2016 and 2019. In parallel, a draft safety report and environmental impact assessment (EIA) were prepared in 2017, resulting in draft preliminary consent being obtained from the Slovenian Nuclear Safety Administration (SNSA). The environmental consent process, which includes a cross-border EIA, began in 2019 with consent being granted in September 2021. The preliminary consent from SNSA and environmental consent led the way to obtaining a construction permit and it is hoped that the process will be completed in 2021 with construction activities then progressing.

Discussion

The EIA report is available from the Ministry of the Environment and Spatial Planning. The EIA consent is separate from the nuclear administration. Some of the safety assessment reports may be available online from the SNSA.

Retrievability is considered as a straightforward option for wastes up until closure of the facility when additional concrete infill will be added that would make retrieval more complex, but also provide greater confinement.

2.7 WHAT'S HAPPENING AT SKB IN THE NEXT DECADES?

Ulrik Kautsky (SKB) presented.

There are numerous ongoing activities within the biosphere team at SKB. The current research and development program was translated into English and published as SKB report TR-19-24. The program has recently been approved and the next program is now due to be written and submitted by September 2022.

SKB is responsible for all radioactive waste in Sweden, including its transport from facilities, interim storage and disposal. There is currently one operational repository for short-lived radioactive waste (SFR) at Forsmark and an application to construct a high-level waste repository for SNF at Forsmark was submitted in March 2011 (SR-Site). Several years after the SR-Site submission, SKB continued to address questions of the submission and an Environmental Court hearing took place in 2017. The final recommendation from SSM to the Government of Sweden was issued in January 2018. The final Government decision is still pending, and it had been hoped that this would be given by the end of 2021, but the Government has recently said that additional data are needed, although it is not yet known what the new data requirements will entail. As such, it may be necessary to plan for an increased capacity at the central interim storage facility for SNF, which is contrary to the recommendations from regulatory authorities and is not favoured by the local community.

The lack of a final decision on the final repository for SNF has affected the SKB board, which is comprised of the nuclear power producers, with the delayed decision leading to budget cuts and the possibility of several more years of delay to the overall programme. The long-term implications on SKB in terms of budget are not currently known. Work to update the safety assessment is ongoing, although no new biosphere report is being prepared as part of the updated assessment. Plans for future assessments may, however, include updates to how the biosphere is handled. A program for continued site investigations is also being developed.

A final repository for long-lived ILW (SFL) is planned and a concept study was finalised in 2020, along with a preliminary safety evaluation. The repository will include some difficult wastes and there is potential for high doses compared to the other wastes/disposal concepts. New methods for modelling transport of radionuclides to the biosphere were considered in the preliminary safety evaluation. SSM has reviewed the preliminary safety evaluation even though it was not a formal application and work is now underway to look at how review comments can be taken into account in the next round of assessments. An official response from SSM is awaited with regard to SFL and the programme may be put on hold.

The operational SFR facility for short-lived radioactive waste is located at a depth of 50 m in bedrock below the sea and an application to extend the facility to accommodate dismantling wastes is being submitted. A new safety assessment report for the extension is being developed and should be ready for internal review by the end of 2021. Overall, the assessment looks similar to previous iterations, but the content has changed. A more iterative approach to assessment has been applied, as developed for the enhanced BIOMASS methodology (see Section 4.1). The overall approach has now been applied in seven previous assessments (SR-97, SAFE, SR-Can, SAR02, SR-Site, SR-PSU and SE-SFL); this is now the eighth iteration, so there is good knowledge to draw upon but also new information to take into account, such as new scientific developments and understanding and the views of the authorities that have reviewed previous assessments.

Climate is a particular area where there are updates to take into account. New IPPC climate updates are available and need to be taken into account. A new present-day climate variant without a cooler period is included, along with a warm variant that has an extended early submerged phase and a cold climate variant that has a short early submerged phase followed by temperate and periglacial phases. The delineation of 'biosphere objects' has also been reviewed with careful attention being given to alternative approaches that could be applied. Potential discharge points have also been focussed upon, taking into account shoreline displacement. Many discharge points are focussed within a single biosphere object.

The biosphere transport and exposure model (BioTex) has also been updated to include greater vertical discretisation. Several calculation cases have been analysed and preliminary results indicate that, in the early phase after closure, doses primarily arise as a result of exposure to C-14 with Mo-93 and Ca-41 then dominating over time. There is little retention of C-14 in the system, so the majority is exported and there is considerable decay on the timescale relevant for the assessment. A similar situation occurs for Mo-93, but there is retention in lower regolith layers where decay then occurs.

Shoreline displacement is central to the assessment. As new shoreline emerges, lakes form that infill over time as shoreline mires grow. Drainage of mires for agricultural use gives rise to the highest potential doses. The identification of areas that could support future wetlands has, therefore, been an important focus. Focussed 3-dimensional modelling of potential groundwater discharge points has also been undertaken, looking at how they change under different peat scenarios (base case, no peat and high peat cases). Where peat is absent, there tends to be a more focussed dispersal of streamlines entering the regolith and reaching the surface.

Field studies have also been progressed at Byle gård, a natural analogue for the future situation at Forsmark around 3000 AD. The site includes a former lake that is now partly mire and soils have been subject to leaching since terrestrialisation. Agricultural crops have been cultivated, including tubers, root vegetables, cereals, leafy and non-leafy vegetables, legumes and pasture both with and without the addition of fertilisers, to study element transfers. Large variations are observed in the results depending on the type of crop and the soils on which they are grown.

A lot of work is therefore continuing within SKB and the working hypothesis is that this will continue into the future.

Discussion

For SFR, the evidence points to releases occurring primarily to one future biosphere object, although consideration is also given to alternative release objects and different landscape types.

2.8 UPDATE ON THE UNITED KINGDOM LOW LEVEL WASTE REPOSITORY

James Ridehalgh (LLWR) presented.

The LLWR has been in operation since 1959 with tumble tipping of waste from the Sellafield site into Trench 1. Trenches 2 to 5 then operated until 1997 when an interim cap was constructed. After this, there was a move to container waste disposal within vaults, the first of which (Vault 8) began in 1998. Vault 9 then began to accept disposals in 2010 and an area of the site has been set aside for future vault construction.

The LLWR is currently in a transition period. In July 2021, LLWR became a subsidiary of the UK Nuclear Decommissioning Authority (NDA), combining with Radioactive Waste Management (RWM) capabilities to form a new NDA waste division. This division, which will operate from January 2022, will be accountable for capabilities across the entire radioactive waste cycle. This will include major infrastructure delivery (e.g. of a geological disposal facility), optimisation of the waste inventory and balancing supply and treatment options with disposals.

The main programme ongoing at LLWR at the current time is the repository development programme and, specifically, final capping of the disposal area. Vault 8 has been open since 1998 and some containers are showing signs of degradation. As such, there is a need to build-up profile levels at the northern end of the disposal area prior to capping. The cap with then be extended over the other vault areas as they fill up and over the trenches that currently have an interim cap in place. The final cap will have a domed shape and will consist of various layers, including some impermeable layers.

The implications of the capping load on emplaced wastes have been investigated to ensure there is sufficient strength the withstand capping loads or to consider what additional strengthening is needed prior to capping. Results have indicated that there is not enough strength in containers to prevent final capping resulting in deformation, with risks increasing with traffic loading and a ‘squashed box’ effect could occur in some areas. This could be up to tens of centimetres in some areas but would not be consistent over the whole vault area and the timing of occurrence is also likely to be variable. The extent of deformation in any area would depend on factors such as the content of disposal containers, and presence or corrosion and/or air gaps. The design of disposal containers has also changed over time which may have an effect. Any settlement caused by container deformation may affect cap resilience and surcharging (adding weight) to Vault 8 containers will help to address possible settlement before capping.

Site works are currently preparing for surcharging. Materials required will be brought in from off site by rail and an area has been readied for receipt of material. Infrastructure for the movement of materials to where they are needed has also been installed. A stockpiling area has also been made ready for capping works. Surface water lagoons are also being constructed for the capping area and traffic lights have been installed on the haul road to address health and safety risks associated with construction versus daily work demands.

The haul road was routed through some areas associated with previous Royal Ordnance underground infrastructure and it was necessary to undertake some site characterisation works. These works identified some non-radioactive contamination that is in the process of being remediated.

Historical storage of plutonium contaminated Royal Ordnance magazines has led to the contamination of some buildings on site and there is a 10-year project ongoing to remediate those buildings and the concrete inside the magazines. That project is now coming to an end and is moving toward the building demolition phase. Reassurance work around the footprint of the buildings has been undertaken with surveys finding some Cs-137 contamination hotspots. In looking back at the history of the site, the hotspots are associated with an old haul road, so it is likely that they arose as a result of historical spillages. Some remediation work will be required to clean up these areas.

The NDA has recently asked LLWR to consider whether or not the site would be suitable to host a near-surface disposal facility such as a silo or enhanced vaults. No decision has yet been taken, but optioneering studies are underway to consider what would be possible at the site, as input to the decision-making process. A concept silo has been considered as part of this with the silo being 100 m in depth with waste emplaced in the lower 30 m. The whole site was considered in terms of potential siting for a silo but this has subsequently been revised to focus on the main operating area of the site. Work has now progressed concerning how the silo design could affect groundwater flow at the site, as dewatering would be required during construction. Potential interaction of the silo with trench disposals is also being reviewed, considering different combinations of silos and wall designs on groundwater levels.

The LLWR site has been operational for a long time and numerous boreholes have been drilled across the site. Most of these have been drilled in shallow drift deposits with only a small number being drilled into the sandstone bedrock beneath Quaternary deposits. Information on the underlying geology of the site is therefore limited and additional works have been undertaken over the previous 12 months to develop a better understanding of the site geology. Passive seismic surveys were undertaken at various points across the site in October 2020 that provided greater detail about the bedrock surface. Results show drift deposits of around 30-40 m depth, so any silo would be constructed partly in bedrock and partly in drift deposits. Furthermore, detailed seismic surveys were undertaken early in 2021. The surveys were performed at night to avoid noise from construction traffic and resulted in a much more detailed contour map of the bedrock. This shows that an extensive fracture system is present in some areas, but others have good quality bedrock. Work is ongoing to further interpret the data and to investigate whether faulting has affected the Quaternary deposits above the bedrock.

Deeper boreholes are also being drilled on site (up to 120 m depth) to gain more data on bedrock properties and pumping tests are planned. Once data are available from these tests, hydrogeological models of the site will be updated.

Feasibility studies for near-surface disposals are due to be completed by June 2023 and the next update on the environmental safety case (ESC) for the site is due to be submitted in 2026. If additional near surface disposal is to be included in the ESC, a decision will be needed in 2024. Approval of a business case for that work will also be required. A planning application would not be required until after the ESC has been submitted. If additional near surface disposal does go ahead at the site, no physical construction is expected until around 2030.

Discussion

It had not been intended that Vault 8 would be open to the elements for the length of time that it has, and this has resulted in the degradation of some containers. If weight is placed on top of the containers, they may be compressed or collapse to an extent. The idea of surcharging is, therefore, to cause this settlement to occur in a controlled manner by adding weight and helping to protect the performance of the final cap. Following settlement, the area can then be built back up to the intended height prior to final capping.

"Bath tubbing" has been considered as a scenario for the site. It has been accepted that this could occur and it has therefore been built into the safety case.

Due to the long and complex history of the site, records have been useful in order to explain hotspots of contamination etc. However, it can be difficult to know where to look to gain the information required. Knowledge management is therefore a real issue and needs to be worked on to achieve time efficiency.

2.9 NWMO UPDATE AND SCREENING ASSESSMENT

Antoine Boyer & Mark Gobien (NWMO) presented.

NWMO is currently in a site selection phase for a geological disposal facility for spent nuclear fuel (SNF) and the intention is to select a site by 2023. Two potential sites are currently subject to site investigation works, including baseline studies for biodiversity etc.

As information becomes available from the site investigations, site-specific safety assessments are being developed. A new integrated system model is also developed at the NWMO, with site-specific hydrology and refinement of potential exposure groups and their exposure pathways to be more site-specific.

An updated contaminant screening assessment has recently been completed, taking into account updated inventories of radionuclides and elements in SNF. The screening analysis is used to identify the key radionuclides and elements for more detailed safety assessment. The analysis feeds into assessment models, and informs the site characterisation programme and technical / research programmes.

For radionuclides, a simple screening criteria approach has been applied whereby any radionuclide contributing >0.1% of the total radiotoxicity of the inventory are screened-in.

As the screened-in radionuclides are used in pre-closure and post-closure assessments, including inadvertent human intrusion and non-human biota dose assessments, it is important to ensure that they cover all the potential exposure pathways and considerations for these assessments, as illustrated in Table 3. A key distinction between the different assessments is the fuel age considered. Important exposure pathways also differ. For pre-closure assessments, volatiles and particulates require special attention, whereas fission and activation products are of particular interest for post-closure assessments.

Table 1. Considerations for radionuclide screening for different assessment purposes.

Assessment	Inventory data	Pathways	Special considerations
Pre-closure	10-30 year old fuel	Ingestion Inhalation Air immersion Ground shine	Volatiles Particulates
Post-closure	10^3 – 10^6 year old fuel	Ingestion Ground shine	Fission / activation products Actinides
Inadvertent human intrusion	300 – 10^6 year old fuel	Ingestion Inhalation Ground shine	n/a
Non-human biota	30 – 10^6 year old fuel	Internal Water immersion Soil immersion On-ground Above-ground Air immersion	Maximally exposed biota

Site-specific data were not taken into account in the screening analysis. Rather, the focus is on dose conversion factors for humans (ICRP publications 119 and 144), dose coefficients (DC) for a range of non-human biota (ICRP Publication 136), and taking into account the relevant exposure pathways. The maximum DCs were selected for screening to be conservative and ensure all species of relevance were considered.

Following the radionuclide screening, the screening of stable species was completed. Some elements were excluded at the outset, including inert gases and common or essential elements such as carbon, hydrogen, nitrogen, oxygen and silicon. Transactinide and actinide elements were also excluded, with the exception of uranium which is known to be both radiotoxic and chemotoxic. Elements only present as radionuclides were also excluded. The remaining 99 elements in the periodic table were included. Contaminant degradation is less of an issue for chemicals, so the maximum inventory for each of 99 elements was selected over time as input to screening.

For screening of stable species, dose conversion factors and DCs are not available, so environmental media criteria were developed for surface water, groundwater, soil, sediment and air. Chemical hazard differs from radiotoxicity in that criteria are typically developed both for the protection of humans and the environment, which can then be assessed simultaneously.

Tiered regulatory guidance is available in Canada on sources of environmental media criteria to apply. Where available, criteria from the Canadian Council of Ministers of the Environment were applied. In their absence the following sources, in order, were consulted:

- other federal and provincial guidelines (e.g., Health Canada, Ontario Ministry of the Environment);
- other provincial, territory or jurisdiction guidelines; or
- derived criteria / analogues.

All sources were consulted to identify appropriate criteria. However, information is not available for all elements in all environmental media of interest, and it was therefore necessary to derive criteria or assign analogues (e.g. by substituting one rare earth element for another) to address data gaps.

The radionuclide screening analysis identified 59 unique radionuclides across all assessments. For pre-closure assessments, 27 radionuclides were screened-in and 40 were screened-in for post-closure assessments. For inadvertent human intrusion, 38 radionuclides were screened-in. No additional radionuclides were screened in specifically for non-human biota assessments. For the chemical hazards screening, 17 elements were identified for detailed assessment. The results are comparable to previous screening assessments completed by NWMO and those of other waste management organisations.

A report on the screening analysis will be published on the NWMO website (www.nwmo.ca).

Discussion

It is important in undertaking screening analyses of radionuclides to consider decay series so that potentially radiotoxic progeny are not excluded on the basis that they are not explicitly included in the initial waste inventory.

2.10 TOWARDS AN ECOLOGICAL MODELLING APPROACH FOR ASSESSING RADIOLOGICAL IMPACT ON WILDLIFE POPULATIONS

Jordi Vives (SCK·CEN) presented.

The emphasis of the ICRP framework for protection of the environment is on the protection of populations of non-human biota rather than individuals and work has been ongoing through working groups within the IAEA MODARIA I and II programmes on modelling wildlife exposures and effects. Within Working Group 5, one objective was to produce an improved fit-for-purpose method and supporting data on biota exposures and effects that could support good practice guidance for the IAEA. As a result of work undertaken within this group, it can be stated that assessment tools exist and are relatively straightforward to apply. However, their output can only be compared against screening dose rates and there are questions as to how good these are in terms of a population protection endpoint and what to do if screening dose rates are exceeded. As a result, there has been discussion within the MODARIA working groups on potential effects of radiation on populations and a population model was developed with the objective of generating advice around the evaluation of risk criteria for populations. The work aimed to provide information in support of stakeholder dialogue around factors affecting population responses to radiation and the ecological relevance of current protection criteria.

The radiation effects modelling work aimed to address a number of questions, including the following.

- Can population modelling provide arguments to support the robustness of benchmarks?
- Do the ICRP derived consideration reference levels (DCRL) that are based on effects in individuals apply to populations?
- At what dose rate can effects at a population level start to be seen when in the presence of other stressors?
- What percentage of a population in an area of an ecosystem needs to be affected in order to affect the whole population?
- Is there new experimental evidence to test models, such as non-targeted effects (NTEs) and historical doses?

In addressing these questions, the aim was to consider whether general recommendations could be produced.

For NTE and historical doses, data sets from Chernobyl and Fukushima were sourced. It can be difficult to understand transgenerational effects in populations at non-acute dose rates with limited studies, but there is some evidence that such affects can be induced. For example, there is some evidence from Chernobyl that past accidental acute exposures may have resulted in transgenerational effects that are being observed at todays significantly lower chronic dose rates that would be unlikely to occur as a result of chronic routine low-level discharges.

Population modelling methods were reviewed with population models identified and life history information for the ICRP reference animals and plants were collated. Both matrix and ordinary differential equation (ODE) approaches were considered, with the ODE approach, which can combine radiation effects with ecological processes, being selected. A model was developed that took into account factors such as reproduction rate, carrying capacity, survival, damage and death along with recovery and repair, in order to evaluate radiation sensitivity within a population. The basic repair model includes a repair pool that can mediate recovery from sick to healthy. On the basis of model results, it was concluded that the available benchmarks (i.e. the ICRP DCRLs) are reasonably protective of populations.

Some legacy sites such as those associated with naturally occurring radioactive materials (NORM) have low levels of radioactivity mixed with higher concentrations of chemical pollutants and there is interest in understanding whether or not risk assessments for the different contaminants are consistent. There is also interest in what we can learn from ecotoxicology modelling approaches that may help further understand how toxicological processes may combine with ecological factors at the level of the population. Ecotoxicology models were therefore reviewed, and it was found that assessors extrapolate from laboratory data to effects in the field in the same way as we do in radioecological modelling (i.e. by applying safety factors to account for uncertainties). Furthermore, population models are not routinely used in either ecotoxicology or radioecology for regulatory assessment purposes due to their perceived complexity and uncertainties. However, it is considered useful to apply population models to test whether current approaches used for regulatory purposes are appropriate by verifying the robustness of benchmarks.

A population model was set up for a population of Chernobyl Red Forest field voles that took into account the ecological context and considered radiation effects. A simple modelling approach was applied with the aim of identifying phenomena that could increase the sensitivity of a population to radiation exposure.

In terms of important population phenomena, the migration of individuals from non-contaminated areas is an important driver for population restoration in areas affected by an accident. Newly immigrated individuals can become sick as a result of exposure, but the model indicates that the population steadily recovers over around 3 years. Adaptation was not found to have a large impact on the recovery of the population, but this could be different for less mobile species. On the basis of model results, it was concluded that ICRP DCRLs were sufficiently protective in the ecological context studied. The model and its application are reported in Vives i Batlle et al. (2020)[g].

The field vole population model is now being considered as a candidate model for development in order to look at the combined effects of chemicals and radiation and is being proposed for consideration in the follow-on programme to MODARIA.

The main lessons learned from activities relating to exposure and effect modelling in MODARIA are:

- the need to define populations both spatially and temporally;
- population models can be applied to test benchmarks that have not been demonstrably set using population-level effects;
- there is a need to further improve understanding of mechanisms leading to effects at low dose rates; and
- there is a need to improve consistency in population modelling approaches considered in chemical and radiation protection contexts.

The main interest in the work undertaken to date has been to test whether current benchmarks for risk assessment are appropriate when considering the protection of populations as an endpoint through the development and application of population models with the intention of the output being used to inform stakeholder dialogue on population responses to radiation in the environment. Results indicate that populations are more sensitive to changes in migration than they are reproductive rate and that there is a link between dose rate, migration rate and population sensitivity.

A simple candidate model is available for comparing chemical and radiation responses, but this needs to be validated, which is a task proposed for inclusion in the follow up to the MODARIA programme that

[g] Vives i Batlle JV et al. (2020). Modelling the effects of ionising radiation on a vole population from the Chernobyl Red forest in an ecological context. Ecological Modelling, 438: 109306.

would allow the consequences of mixed chemical and radiation exposure to be explored. Additional possible follow-on tasks could include the development of a set of reference population modelling scenarios under different exposure situations and use of the MODARIA population model output to make a user-friendly advisory tool for evaluating population effects under different situations. A training module could also be developed around the regulatory relevance of population dose effects and the role of population modelling.

Discussion

A starting point for looking at multi-stressor effects is to look at modes of action which can help identify whether effects are likely to be additive. The simplest assumption for modelling is that effects are additive and this is therefore a useful starting point with other effects then being considered. The field vole model has therefore been developed on this basis to illustrate possibilities within a 'template' model. The intention then will be to work with ecotoxicologists to discuss and develop further.

2.11 ERICA VERSION 2.0

Karen Smith (ERICA TS) presented on behalf of Carol Robinson (DSA & ERICA Consortium lead).

The ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) assessment tool was developed as part of a Euratom funded project that ran from 2004 to 2007. The assessment tool guides users through a tiered approach to evaluate risks to non-human biota exposed to radioactivity in the environment. Tier 1 compares activity concentrations in environmental media to pre-calculated environmental media concentration limits (EMCLs) to estimate risk quotients. Tier 2 calculates dose rates to reference organisms and/or user-defined representative species and allows a more tailored assessment to be undertaken that takes account of site-specific information where available. Tier 3 then provides the option to run assessments probabilistically.

Since the initial release of the ERICA assessment tool, the Norwegian Radiation and Nuclear Safety Authority (DSA) has led a group of partners to support the maintenance and continued development of the tool, which has resulted in regular updates, the most recent of which was a version 1.3 release in 2019. Subsequently, in July 2021, a beta test version was released for version 2.0 of the tool. Version 2.0 represents the most significant update to the tool since its original development. Changes include new dosimetry, updates to underlying parameter databases (concentration ratios (CR) and freshwater Kds), inclusion of noble gas dosimetry (including radon inhalation) and the addition of a new function that allows multiple user-defined organisms to be added through an interface with Microsoft Excel. As a result of changes to dosimetry and parameter databases, Tier 1 EMCLs have also been recalculated.

The ICRP dosimetry for reference animals and plants (ICRP-136) has now been incorporated within ERICA with some necessary simplifications. For example, the ICRP approach allows the integration time for decay and ingrowth of radionuclides to be selected relevant to particular assessments, whereas for its integration within ERICA, the integration time has been set to 1 year. Dose coefficients have also been slightly reconfigured so that there is now a single category of 'external on-soil' dose coefficients for terrestrial systems rather than separate categories for different radiation types (external low-beta, external beta-gamma). All short-lived progeny in decay series are also included explicitly rather than including progeny within the dose coefficients for parent radionuclides (where progeny have a half-life of 10 days or less) and a media average activity correction factor has been included to account for decay of the unsupported component for short-lived radionuclides over the integration period.

In updating CRs, a further new assessment factor has been introduced to address a recognised issue around the application of CRs for stable elements or long-lived radionuclides to short-lived radionuclides. The new equilibrium correction factor is based on a solution for freshwater organisms presented in IAEA TRS 472, but extended to all ecosystems. A new approach to addressing data gaps in CRs has also been added that distinguishes cases where CRs are derived from empirical data for the organism in combination with a surrogate and cases that are based entirely on the use of surrogates.

The update to the freshwater Kd database draws on published information resulting from the data collations undertaken within the IAEA MODARIA programme.

The lack of noble gas dosimetry within ERICA had been noted as a limitation to the tool's application, necessitating the use of alternative models/approaches. This has now been addressed through the inclusion of a suite of noble gases that are available at Tier 2 with immersion DCs from ICRP-136 being applied. Assessment parameters (CR and Kd) are set to zero by default, assuming they neither interact with environmental or biological media. For dose rate calculations, terrestrial biota are assumed to be present 100% of the time in contaminated air irrespective of whether they are located above or below ground.

For radon (Rn-222) and thoron (Rn-220), internal 'inhalation' dose rates are also calculated. The approach used is based on Vives i Batlle et al. (2017)[h]. In the beta test version, emanation coefficients were applied to derive soil air concentrations of radon and thoron from their parent radionuclides (Ra-226 and Th-228, respectively) in soils. For these decay series, inhalation dose rates were only calculated for organisms living within soils. Issues were, however, identified, with dose rates in excess of screening values being calculated for low activity concentrations of the parent radionuclides in soils. This exposure pathway is not routinely considered in human dose assessments and, as such, the decision has been made to exclude radon and thoron in decay chains from the version 2.0 release. Assessors will, however, have the ability to evaluate separately the contribution of radon and thoron inhalation to dose rates to animals[i] using direct air activity concentration inputs for these radionuclides and guidance is provided in the tools help function.

The new 'add organism' wizard that allows multiple new representative organisms to be added for assessment at one time is available within the database of the assessment tool and specific guidance on the use of this function is provided. A structured Excel file is used for entry of the necessary parameters to define new organisms. One important factor in adding organisms using this new feature is the need to accurately assign user-defined organisms to wildlife groups as the wildlife groups are used in automatically assigning default CRs for short-lived radionuclides in decay series. If wildlife groups are not assigned and a radionuclide with short-lived progeny is selected for assessment, then ERICA will not run.

The full version 2.0 release was scheduled for late October/early November 2021 and feedback on the tool and ideas for future development are welcome. The tool can be freely downloaded, following registration, from http://erica-tool.com.

[h] Vives i Batlle, J. et al. (2017). A method for assessing exposure of terrestrial wildlife to environmental radon (Rn-222) and thoron (Rn-220). Science of The Total Environment, 605–606, pp. 569-577.

[i] Internal dose rates to plants are not calculated for radon and thoron.

Discussion

There has been extensive testing and quality assurance undertaken on the beta test version, including comparison of EMCLs and Tier 2 output with that of version 1.3. A report detailing the comparisons and reasons behind differences in output has been prepared and will be made available on the website.

2.12 IDENTIFYING POPULATIONS OF INTEREST. WHY THIS MATTERS FOR DEMONSTRATING PROTECTION OF THE ENVIRONMENT (SOME DISCUSSION)

Graham Smith (GMS Abingdon & Clemson University) presented.

A series of topical points around the identification of populations of non-human biota for assessment purposes were presented to promote discussion.

Radiological assessments supporting protection of the environment typically focus on the calculation of dose rates to individual reference animals and plants (RAPs) and/or reference organisms that are then compared against criteria such as the ICRP DCRLs. However, if populations are the focus of protection objectives, thought needs to be given as to how to link assessments undertaken for individuals to populations. This was discussed in ICRP Publication 108:

*"… {these} population characteristics need to be borne in mind when considering the potential consequences of any assumed or observed effects of radiation. **The geographic area necessary to support populations of these sizes is also of relevance**"* (ICRP, 2008, emphasis added)[j].

Linking a RAP to a population area within a dose assessment is intended to ensure impacts are evaluated at the level of the population, but this may not address the question of whether the population within the specified geographical area is actually of protection interest. Population characteristics and distributions of the real population of interest should therefore be considered when looking at the consequences of radiation exposure on non-human biota. In reality, only a small fraction of a population may reside in a potentially contaminated area, or it may be the opposite, with the population of interest existing only in a small fraction of the contaminated area, e.g. more highly contaminated than the average. In order to address either situation, it would make sense to calculate dose rates in the area relevant to the real population of interest and thereby achieve the relevant spatial averaging of the calculation of contaminant concentrations.

The area of interest is further referred to in ICRP Publication 124 where it is advised that the area of interest for a RAP should be identified in advance and relative to the overall conservation objectives:

"*As the DCRL bands apply to animals and plants within a given location, **the extent of such an area needs to be determined in advance relative to the overall conservation objectives***" (ICRP, 2014, emphasis added)[k].

The potential exposure of biota populations was also considered in the enhanced BIOMASS methodology where it is suggested that, in setting out the assessment context, biota populations are

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[j] ICRP (2008). Environmental Protection - the Concept and Use of Reference Animals and Plants. ICRP Publication 108. Ann. ICRP 38 (4-6).

[k] ICRP (2014). Protection of the environment under different exposure situations. ICRP Publication 124. Ann. ICRP 43(1).

considered as a protection target and that consideration be given to the area required by the population of interest. It is also noted that, in determining the area of interest in the biosphere, assessments tend to focus on higher contamination areas and over spatial areas of relevance to potential exposure groups and populations of potentially exposed non-human biota, which reflects the words from ICRP Publication 124. This suggests that it is not appropriate to calculate dose rates to non-human biota based on the highest concentrations in the system. This approach has been used in a number of assessments, but risks resources being unnecessarily diverted if calculated dose rates exceed screening criteria. However, use of maximum concentrations could be usefully applied within a tiered assessment approach where an initial cautious model based on highest concentrations at any point in space and time within the system of interest and comparison against screening criteria. Nonetheless, it is still worthwhile to consider the spatial area of interest prior to such an assessment since this will ensure transparency in the assessment context and justification of spatial assumptions should there be a need to move to a second tier of assessment.

Some upcoming publications of potential interest were highlighted, including:

- Griffault et al. (submitted). Approaches to the definition of potentially exposed groups and potentially exposed populations of biota in the context of solid radioactive waste. Paper for special issue of JRP, based on inputs from MODARIA II WG6/BIOPROTA members.
- ICRP Task Group reports:
  - TG-97: Application of the Commission's Recommendations for Surface and Near Surface Disposal of Solid Radioactive Waste.
  - TG-98: Application of the Commission's Recommendations to the Management of Exposures resulting from Contaminated Areas that have arisen due to Past Activities.
  - TG-114: Application of tolerability and reasonableness to the protection of the environment (early stages).

The ICRP task groups are all thinking around similar issues, including long-term contexts for exposure.

Discussion

In defining 'populations' of non-human biota, consideration should not just be given to a number of specimens, rather, the target should be to preserve genetics. There has been much discussion within the IAEA MODARIA programmes on how to define populations. Overall, the protection target is to protect ecosystems which encompass a range of different species that interact within communities. With exposure to radiation, some of these species may be removed and their removal may then affect other species within that community that are not affected directly by radiation exposure. There is, therefore, a complex interplay between species and it is recognised that further consideration is needed with regard to biota dose assessments.

Whilst it may be possible to define areas of interest for populations currently present in an area of interest, thought is needed as to how to define the area of interest for a population at times into the future. One approach to address this could be to use analogue sites. This will however be an assessment-specific question. A key point in raising the issues around areas of interest is to guide assessors away from the use of human-assessment based calculated media concentrations as input to biota dose assessments without due consideration of the appropriateness relative to the protection targets.

One approach that is being applied in assessments is to identify niche species of interest both scientifically and in relation to stakeholder interests and to then work to ensure these species and biodiversity/ecological concerns are explicitly integrated in assessments where possible. Where this isn’t possible, the use of surrogate species may be feasible.

3. PRESENTATION IN SUPPORT OF ACADEMIC MEMBERSHIP

The University of Eastern Finland (UEF) expressed interest in academic membership of BIOPROTA and were, therefore, invited to present on their research activities and interest areas aligning with those of BIOPROTA, to support a decision on membership during a subsequent meeting of the BIOPROTA Sponsoring Committee.

3.1 FATE OF RADIONUCLIDE C-14 IN SOIL-PLANT-ATMOSPHERE CONTINUUM: UEF ACTIVITIES IN SUPPORT OF ACADEMIC MEMBERSHIP

Christina Biasi (UEF) presented.

The department of Environmental Science at UEF has an interest generally in nutrient cycling, including carbon and nitrogen, in northern ecosystems but also has a specific project (KYT) looking at the fate of C-14 in the soil-plant-atmosphere system. This is a Finnish-funded research project relating to C-14 in nuclear waste.

In terms of general carbon cycling, there is interest in developing greater understanding of how much and when carbon is taken up by plants, how carbon is stabilised in soils and destabilised and turned into carbon dioxide by the action of soil microbes, and how environmental change (e.g. land use and climate change) affect carbon cycling.

C-14 is a significant radionuclide for low and intermediate level radioactive waste and spent fuel and knowledge is therefore needed on its environmental migration and behaviour. However, C-14 is naturally present and it can, therefore, be difficult to trace sources. C-14 signatures in soils can be used as a tracer due to older soils (e.g. aged peatlands) having depleted C-14 signatures compared to modern soils – the older the soil, the more depleted the C-14 signature. This can enable C-14 to be used as a tracer to study the movement of soil carbon into plants and several studies have been performed to look at this, including on grass and tree species growing on former peat extraction sites in Eastern Finland. Both field and laboratory studies have been performed with C-14 analysed in soil, atmospheric carbon dioxide, roots and leaves of plants, and soil animals by accelerator mass spectrometer (AMS) to investigate the extent to which C-14 signatures in soils transfer to plants and animals. The analysis of C-14 in soils is costly (around 300 Euros per sample) so the number of samples analysed was therefore necessarily reduced by mixing soil samples.

A clear soil signal was detected in canary root grass in field studies indicating that up to 2% of carbon was obtained from soil by root uptake. Soil derived carbon content in tree roots was higher at around 5%. The results generally correspond to literature values in terms of root uptake of carbon, but are slightly elevated. The difference between root uptake in grass and trees may be due to the presence of mycorrhiza which could lead to some direct additional intake to tree roots. In laboratory experiments, root uptake was found to be around four times lower. The absence of mycorrhiza in the laboratory experiments might help explain the lower uptake. No soil C-14 signal was detected in the leaves of grass or trees. Whilst a soil C-14 signal was detected in canopy air, no leaf imprint was detected. This could be due to leaves growing mostly from the top of the plants where greater air mixing occurs. There is interest in looking further into this in the ongoing project. The results of the soil to plant transfer studies are reported in Majlesi et al. (2019) [i].

[i] Majlesi S et al. (2019). Transfer of C-14 from soil to plants. Environmental Science & Technology 53: 4198-4205.

Results of the study of C-14 transfer from soils to animals are reported in Majlesi et al. (2020)[m]. Earthworms showed a high C-14 soil imprint of around 20% of total carbon and soil microbial biomass was also heavily influenced by soil carbon (>60% of total carbon). However, other soil animals (spiders, ants etc.) showed no soil carbon signal. The greatest soil signals are therefore associated with biota living in soils and directly exploiting organic matter from within soils.

As a result of the need to mix soil samples for analysis, it was not possible to look at seasonal dynamics in the studies. There has therefore been interest in finding a soil-plant system that can be studied in more detail using C-13 as a natural tracer which is cheaper to analyse. Such a site has been identified in Iceland, which is associated with high levels of volcanic activity. Both carbon dioxide and methane are released from volcanic-geothermal fields that have distinct isotopic C-13 signals that are ideal for studying uptake within and through the biosphere. This is to be the focus of a new project (NAT-LAB-14C) at UEF to investigate the transfer of deep geological carbon sources into terrestrial food webs. The uptake of C-13 (as a substitute for C-14) by plants will be investigated, as well as uptake by consumers such as sheep and horses. The project will also look at the amount of methane that is oxidised to carbon dioxide in soils in different systems (e.g. wetlands with anaerobic profiles and other more aerobic profile systems). The project consists of four work packages:

- Work package 1: uptake of C-14 into plants;
- Work package 2: C-14 exposure to grazing animals;
- Work package 3: methane oxidation rates in wet and dry ecosystems; and
- Work package 4: assessment-level and process-based C-14 transfer modelling.

The Icelandic site was visited in June 2021 and samples were taken for analysis. Those samples are currently being analysed and results should soon be available. In a preliminary study, C-13 enrichment was measured and some plants were seen to carry a C-13 signal from soils, but this will be further investigated in the ongoing project.

In addition to the terrestrial C-14 projects mentioned, aquatic C-14 studies are also underway at UEF within the RABIO (Improved Radioecology for Biosphere Modelling) project that is looking at the transfer of elements from sediments to the aquatic food chain, including C-14.

Discussion

The work presented is very relevant to ongoing work within BIOPROTA and the geothermal work underway within the NAT-LAB-14C project is very interesting. Gas fluxes associated with geothermal vents can be sufficient to stimulate both microbial and plant communities. Work previously undertaken at a site in Italy showed a double response to carbon dioxide from a geothermal vent. An initial stimulation of growth was observed, but at higher carbon dioxide concentrations the growth rate was reduced. It is therefore important to consider the detailed patterns of growth with respect to emission responses. Methane can also stimulate and inhibit microbial activity in soils.

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[m] Majlesi S et al. (2020). Transfer of C-14 from soil to animals. Journal of Environmental Radioactivity 225: 106450.

4. ONGOING BIOPROTA WORK PROGRAMMES

4.1 STATUS OF THE ENHANCED BIOMASS METHODOLOGY REPORT

Russell Walke (TST) presented.

Working Group 6 (WG6) of the IAEA MODARIA II programme has developed an enhanced BIOMASS methodology, supported by a BIOPROTA project that ran in parallel to provide technical contributions.

The original BIOMASS methodology was developed as part of an IAEA research programme that completed in 2001. It was published as an IAEA report in 2003[n]. The methodology has been applied widely in assessments and is seen as providing helpful guidance for undertaking and presenting biosphere assessments for radioactive waste disposal facilities and in building confidence that important aspects have not been overlooked. There were, however, some limitations in the original methodology. For example, change or transitions in environments were not considered in any detail. Furthermore, there have been numerous scientific developments since its original publication (e.g. in explicit demonstration of environmental protection and in understanding the behaviour of individual contaminants in the environment) and lots of experience has been gained in undertaking biosphere assessments in a wide range of contexts. As such, it was considered appropriate to revisit the methodology and to enhance it, where appropriate, in light of new knowledge and experience.

The BIOPROTA project in support of the enhanced BIOMASS methodology began in 2016 and was financially and technically supported by a wide range of BIOPROTA member organisations. The work programme was coordinated with that of WG6 with the objective of enhancing the original method rather than providing a fundamentally different methodology. As such, the work flow remains consistent with the original methodology but there is greater emphasis around the iterative nature of assessments, links to the overall safety assessment, and the importance of system understanding within the overall assessment process.

Both the BIOPROTA project and WG6 concluded in 2019 with the submission to the IAEA of a draft TECDOC. At the time of the report being submitted to the IAEA the intention had been for a supplementary BIOPROTA report to be published. However, feedback received from the IAEA on the report in 2021 was that the report was good, but would benefit from the supplementary material being included as appendices rather than as a separate document. As such, a new annex to the report has been developed and submitted. This was recognised as helpful information by the IAEA and some further comments have been received. The aim was for those comments to be fully addressed by the end of 2021.

The IAEA has expressed interest in changing the publication from a TECDOC to a higher level of document in recognition of the guidance provided, but there is concern that this would further delay publication. This could, however, be addressed through the publication of papers planned within a special issue of the Journal of Radiological Protection and a series of papers have been submitted.

[n] IAEA (2003). “Reference Biospheres” for solid radioactive waste disposal. Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (BIOMASS) Programme. IAEA-BIOMASS-6. International Agomic Energy Agency, Vienna.

Following on from the MODARIA II programme, the IAEA is organising a follow-on project that will focus on methods, training and mentoring for radiological and environmental impact assessment. The scope is under development but it is likely it will once again be a 3- or 4-year collaborative programme. Unlike previous programmes, there will be less focus on the production of TECDOCs and there will likely be less of a research element.

4.2 C-14 PROJECT UPDATE

Mike Thorne (TST) presented.

The current BIOPROTA project on the 'Transport of C-14 in the biosphere' has recently delivered the first project milestone - a technical note presenting a review of the biogeochemical carbon cycle, undertaken by members of the project Technical Support Team (TST). The report covers a wide range of source terms since there are many materials disposed of that include C-14. The overall geochemical cycle of carbon is also described with pools and fluxes defined. Systems of particular interest for assessments are then focussed on in more explicit detail. Summary conclusions are also provided that will be expanded and built upon following discussion with sponsoring organisations at the next project meeting to be held following the annual BIOPROTA meeting.

The main source terms to the biosphere will be carbon dioxide and methane either carried in solution or bulk gas, with sources including:

- Graphite: Mainly carbon dioxide plus small amounts of carbon monoxide and volatile organics;
- Uranium: Theoretically mainly methane from uranium carbide, but this has not been observed;
- Iron and steel: Methane, ethane, propane, propene, butane and C5 compounds;
- Aluminium: Methane; and
- Ion-exchange resins: Small amounts of formate, acetate and carbonates.

Much of the report therefore focusses on carbon dioxide and methane as the main forms of C-14 entering the biosphere, but there is also some consideration of carbon monoxide. This is not a significant gas in terms of releases to the biosphere, but it is of interest as it is effectively taken up by foliar pathways.

In reviewing the overall geochemical cycle of carbon, the intention was not to dig into the primary literature, but to synthesise as much information as possible from recent text books. Both unperturbed and perturbed global carbon cycles were considered, which illustrates just how large the fossil fuel reservoir is compared with carbon pools of relevance for assessment purposes. Perturbations cannot, therefore, be considered to be irrelevant.

In moving to particular systems of interest, the types of microbial processes of importance for carbon cycling and different populations of microbes are considered. In agricultural environments, soils are largely aerobic so methane oxidation is of real interest. Microbes that oxidise methane to carbon dioxide are almost always present in soil and any increase in the methane flux can stimulate those microbes which in turn stimulates oxidation rates. Oxidation is not instantaneous, potentially taking several hours. The reaction is non-linear and kinetics of oxidation can be characterised by a 'velocity' of reaction and a Michaelis constant. There may also be a threshold methane concentration below which methane oxidation ceases. The kinetics differ between microbial cultures and soils. The processes and kinetics have been extensively explored in studies funded by RWM. From results, it is evident there are a wide range of timescales in the system that are relevant to assessment models and that should be addressed either through equilibrium assumptions or through kinetics. Similar issues and processes also arise in forest environments.

For domestic animals, equilibrium and biokinetic models have been compared. Energy requirements can be estimated based on metabolizable energy requirements and the carbon content of tissues and organs can be estimated based on data for humans.

For forest ecosystems there are some interesting differences. Periodic harvesting can be followed by rapid increases in biomass production as recovery occurs on timescales of years to decades until standing biomass reaches relative maturity. There is more structure associated with the canopy, so both the upper canopy and lower understorey need to be considered, along with the carbon dioxide and light gradients that occur within and between these. Whilst many processes are similar to those in agricultural systems, the rates and amounts vary significantly. For example, there can be substantial dead wood and litter layer carbon pools present that would largely be absent from agricultural systems. There can also be considerable differences between different forests, such as those growing on wet and dry soils. There can also be considerable seasonal variations in water table position and dissolved organic carbon (DOC) production and transport.

There is a wide range of terminology used for wetland ecosystems, including mires and peatlands and the review has not attempted to capture all of them. For example, brackish and saline wetland systems are not fully addressed, nor are areas that relate to gradients between different zones.

Wetlands tend to be associated with strong vertical variation in redox potential that can vary both spatially and temporally. As such, at least a 2-layer system is required to describe retention and transport. Litter degradation with depth varies considerably and there is an important interplay between slow diffusion in water logged systems and rapid diffusion in the air system. This leads to a useful concept that production and diffusion of methane can work together efficiently at the water table fringe where production can occur but diffusion is not inhibited by waterlogging. Oxidation of methane can then occur as in agricultural soils. Aerenchyma can provide an important transport pathway for the release of methane but also in bringing oxygen to the system.

The natural scales for freshwater systems are the surface water catchment area and sub-catchments. The drainage network within the catchment areas is fairly fundamental to the import and export of carbon both in dissolved form and in solid form as suspended sediment or bedload. One of the key issues for carbon in freshwater systems is the exchange of inorganic carbon between streams and lakes and the atmosphere. Lakes can be either stratified or mixed systems. For stratified systems, stratification can occur multiple times in a year. Unstratified lakes tend to be shallow systems. The review considers turnover, exchange through the food web and loss routes. Lakes can be important regulators for the storage and breakdown of carbon and can be useful source terms for downstream.

Estuaries can be problematic in terms of carbon behaviour as they tend to be highly dynamic systems that change year on year. There are various types of estuary and they are each associated with complex water mixing regimes and high biodiversity. They are therefore complex systems to model. Not only do the influence of physical characteristics need to be considered, but also features such as stratification. The influence of upstream systems is also an important consideration. The sediments in estuarine systems can be anoxic and/or oxic with considerable spatial variation so both carbon dioxide and methane can be produced, depending on the mixing regime.

Coastal and nearshore systems, occupy around 7% of the seafloor and less than 0.5% of the ocean volume, yet they play a significant role in the biogeochemical cycling of carbon, contributing significantly to primary productivity. Sediments of coastal and nearshore systems are also important sinks for both organic and inorganic carbon in sediments. They are also open systems with substantial exchange of carbon across various interfaces with the land, open sea and atmosphere as well as between water and sediments.

At a global level, the biogeochemical carbon cycle has been extensively described in literature and there is good knowledge of the various carbon pools and fluxes between them. The review undertaken focussed on carbon dioxide and methane, but it is recognised that some small organic molecules may also need to be considered in some assessment contexts. The review emphasises the importance of dissolved inorganic carbon (DIC), DOC and particulate organic and inorganic carbon (POC and PIC) pools and the key processes of photosynthesis, respiration, decomposition and mineralisation etc. The review also emphasises the importance of understanding microbially mediated reduction and oxidation in each of the environments considered, as well as the wide diversity of physical, chemical and biological processes that influence the sizes of carbon pools and the fluxes between them. It is important to recognise that, whilst the review includes an extensive reference list, it has only scratched the surface of the available literature since the objective has been to provide high-level explanation of key processes that are operating in the various environments as input to the development of conceptual models. As this progresses in the next stage of the project, additional literature sources may be used to obtain the necessary data to represent the various pools and processes.

5. POTENTIAL COLLABORATION TOPICS

Topical issues identified and discussed during the 2020 annual BIOPROTA meeting were briefly recapped, along with contaminants of interest to motivate discussion of potential subjects for collaboration in BIOPROTA. A brief presentation was also provided on expanding the BIOMASS methodology to address wider issues associated with the management of legacy sites within an 'all-hazards' approach to further promote discussions. A further brief presentation was also provided around electronic publishing within the Journal of Radiological Protection that could provide a useful new means of disseminating BIOPROTA project and workshop output. These are briefly outlined below prior to summarising the overall discussion around potential future collaboration topics.

5.1 CONTAMINANTS OF INTEREST

One approach to identifying potential topics for collaborative work within the forum can be to review contaminants that are important and of common interest for a range of programmes. Where uncertainties and/or new developments are identified for contaminants of common interest, they may be addressed in topical sessions during annual meetings or as specific workshops or projects.

Biosphere assessments typically include several tens of radionuclides of interest and potentially also a range of non-radioactive contaminants. Whether or not these are commonly of interest will depend on the waste inventory and the assessment context. Screening can be useful in identifying lists of contaminants of interest and, typically, a handful of contaminants dominate that need to be represented quantitatively in assessments. However, it is important to cast a broad net to help ensure that potentially important contaminants are not missed and that there is confidence in the resultant list including those contaminants that matter the most.

There is considerable complexity and uncertainty associated with biosphere assessments on long timeframes, so it is helpful to focus effort to understand and constrain uncertainty for the contaminants that really matter. A data protocol from the original BIOMASS methodology has been enhanced as a result of the recent BIOPROTA/MODARIA WG6 project. The enhanced protocol emphasises that the focus of effort should be on information that is important to an assessment and for which data are poorly known or characterised. Some information in assessments may be prescribed by regulations and others might be well characterised, but it is likely that some will be relatively poorly characterised and consideration will need to be given as to whether this matters for assessments. Targeted research around uncertainties can help reduce uncertainties and focus research on aspects that are most important for the calculated endpoints.

Review of wastes and waste forms can identify contaminants of interest and/or regulators may define the types of contaminants that are to be assessed. Where contaminants are consistent and the types of environment and assessment timescales are also similar, this can lead to contaminants of shared interest. Comparison of contaminants of interest for similar wastes can also be useful and provide some confidence that important contaminants have not been overlooked. It is important, however, to be cognisant that surprises can arise. For example, where uncertainties are removed with regard to one contaminant, this can lead to another contaminant emerging as a priority.

During the 2019 annual meeting in Munich, a list of high, medium and low interest contaminants was developed (Figure 1). Many of the contaminants were not a surprise, with some having already been subject to specific BIOPROTA projects or workshops to share knowledge and address uncertainties. However, it is worth considering when projects and workshops took place as understanding continues to progress and knowledge within organisations can change over time so there is value in revisiting the list at regular intervals. It is also worth considering more broadly the contaminants of interest in the long term (i.e. considering also the non-radioactive contaminants of interest). It is already recognised that some non-radioactive hazardous contaminants may be present and need to be assessed and managed carefully, and a series of BIOPROTA reports have been produced around the assessment of non-radioactive hazardous contaminants. BIOPROTA members are therefore encouraged to continue sharing information on radionuclides and other contaminants of interest during the annual meetings to support the identification of commonalities. The list of contaminants of interest will also continue to be reviewed periodically as this also helps to motivate discussion around uncertainties and the sharing of improved understanding around those uncertainties. Where uncertainties remain for contaminants of common interest there is the potential then to develop collaborative workshops or projects as appropriate.

High interest	Medium interest	Low interest
C-14	Se-79	Nb-94
Cl-36	Ag-108m	Sn-126
I-129	Rn-222	Cs-135
Ra-226	U-238, U-235, U-234	Ho-166m
	Tc-99	Gd-151
	Ni-59	
	Mo-93	
	Ca-41	
	Pu-239, Pu-240	
	Np-237	
	Am-241	
	Th-230, Th-232	

Figure 3 List of key radionuclides of interest, as developed during the 2019 annual BIOPROTA meeting.

In discussing the list of high, medium and low priority radionuclides (Figure 1), Po-210 was identified as an additional radionuclide that should be included in the list. It was also noted that, for Andra, Se-79 would be considered as a high interest radionuclide.

In terms of non-radiological contaminants, arsenic, beryllium, cadmium, chromium, mercury, lead and uranium have previously been identified as potentially of interest in assessments.

5.2 APPLYING THE BIOMASS METHODOLOGY TO MANAGEMENT OF LEGACY SITES, LEGACY DISPOSAL FACILITIES, IN SITU DISPOSAL, ON SITE DISPOSAL AND MANAGEMENT OF RADIOACTIVELY CONTAMINATED LAND: ALL HAZARDS APPROACH, PROTECTION OF GROUNDWATER AND OVERALL OPTIMISATION

Graham Smith presented ideas around the application of the enhanced BIOMASS methodology within an all-hazards approach.

The enhanced BIOMASS methodology emphasises the need for a clear assessment context and common understanding within assessment teams and by those commissioning assessments of what is to be achieved, but the questions to be answered are not always well framed. It can also be difficult to obtain support from all stakeholders, requiring a balance between regulatory requirements and endpoints and wider interests/concerns. The need to consider the whole site and develop understanding of that site through a coherent characterisation programme that fully addresses the assessment context is also emphasised. The methodology also highlights the need to integrate safety of people and the environment and for proportionate assessments of chemical and radiological hazards to be undertaken.

Legacy sites often arise as a result of inadequate disposal or storage of wastes and/or contamination left in the ground. Remediation of sites gives rise to new wastes that must be appropriately managed in order for site end states to be achieved.

A Nuclear Energy Agency (NEA) expert group on legacy management has recently produced a report (NEA 7419)[o] that has emphasised the need for the management of legacy sites to be underpinned by safety assessments, noting that, with the exception of trivial cases, the development of a safety case will be an iterative process encompassing a range of areas, including source term data and site and environmental characteristics. The report also recommends the same approach be applied to both chemical and radiological risk assessment, along with comparable risk endpoints, noting that without commonality in approach and endpoints, results cannot be interpreted in a balanced way within a proportionate risk management framework. This means that resources may not be allocated on a proportionate basis and that affected stakeholders cannot be informed about all the implications associated with different options.

Many of the issues / challenges associated with the management of legacy sites are similar to those discussed for radioactive waste management. Programmes can be difficult to organise in light of the issues faced from initial recognition of an issue through to its resolution. Each iteration of a safety case or analysis of options moves toward building confidence around a solution. It is also worth noting that many legacy and waste sites are interrelated.

Ideally, the same protection objectives should be applied to the protection of people, environment, groundwater and other resources, irrespective of the situation (i.e. whether a decommissioning site, waste disposal or legacy site), but an added complexity is the exposure situation. If it is an existing exposure situation such as a legacy site, reference levels are applied. However, for a planned exposure situation, which would encompass new waste disposal facilities, different protection criteria are applied. The difference in the protection objectives applied to different exposure situations can lead to issues around radiation protection.

Common assessment approaches are therefore needed and there are issues around standards that need to be addressed. BIOPROTA is not the place to address standards, but can provide a useful framework for sharing experience about how compliance with standards can be assessed. The BIOMASS methodology provides the right style and ideas, but the scope is too narrow to provide a solution for these broader contexts. It is therefore suggested that the methodology could be extended in scope to cover other relevant aspects, including topics as to support for decisions between recovery of wastes and leaving *in situ*.

There is a need for an approach that can help identify where efforts should be focussed in order to achieve risk reduction that will ideally work on a graded and proportionate basis across all risks. The screening of radionuclides and non-radioactive contaminants is also required on the same basis in order to ensure the focus is on what matters and that sites are characterised to support understanding around

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[o] NEA (2019). Challenges in Nuclear and Radiological Legacy Site Management: Towards a Common Regulatory Framework. NEA 7419.

the migration and accumulation of relevant contaminants. The suggestion of organising a workshop around this topic was made previously to share experience on the use and effectiveness of different hazard indices for radionuclides and other hazardous substances. Initially it had been intended to hold such a workshop in 2021, but this is now suggested for 2022. The idea would be to focus on already identified radionuclides and non-radiological contaminants of interest and draw upon experience from assessments that have been undertaken, such as by NWMO and RWM, in order to focus on key areas of interest. Based on knowledge and experience shared, it may be possible to then prepare advice on the design of a hazard index.

There is also scope to widen interaction on this topic. For example, thematic area 3 of the new IAEA MEREIA project includes consideration of non-radiological aspects in decision making and the regulatory process. The NEA has also established a new expert group to develop an holistic process for decision making on the decommissioning and management of complex sites. There may be a role for BIOPROTA to support both of these programmes with considerations around how to design assessments that support the overall management process.

5.3 REPORT AND PAPER PREPARATION, ELECTRONIC PUBLISHING AND PRINT-ON-DEMAND OPPORTUNITIES

Mike Thorne presented as the current deputy editor of the Journal of Radiological Protection (JRP) and the editor in chief from 2022.

The JRP is moving to electronic publishing, which is also the case for many other journals. From January 2022, JRP publications will be in electronic format only and the website is being developed around this.

BIOPROTA produces a wide range of reports and papers and the developments in publishing formats available, such as e-journals, open access publications etc. could provide a wider opportunity to disseminate project and workshop reports etc. The move to electronic publishing means that there are less restrictions on the length of publications and more variety in formats etc. will become the norm in technical literature. Current articles that are being published are already more diverse in JRP than in many academic journals, with editorials and invited editorials also being published. Supplementary material can also be better integrated within online publications. Reviews and research papers (more like Nature articles) can also be published, along with opinion pieces that provide points of view on particular topics. Book and report reviews as well as news and information on projects are also possible to publish and BIOPROTA reports could be included in such a section.

With freedom from print, the distinction between primary and supplementary information is weakened so large data sets, multi-dimensional figures etc. can all form part of a submission and be subject to the overall review/referee process. Those accessing information published within the journal are then aware that all material has been subject to peer review.

A further advantage of the move to electronic publishing is that publication is rapid following acceptance as there is no need to wait for the next issue to be published in order to assign page numbers. It is also much cleaner to correct any issues as the current version is the referenced version. Collections of papers can also be easily created, which can be historic paper compilations or new compilations.

Whilst JRP is moving to electronic publishing, it will be possible to have hard copies as print-on-demand will be developed in parallel, allowing printed copies to be ordered as required. This would enable nice ‘books’ to be printed, such as anthologies of papers on specific topics (such as a recent special issue on a DSA-led Tromsø workshop on legacy sites or the planned special issue of papers from the IAEA MODARIA programmes etc.).

Suggestions on the types of submission that would be of interest for JRP are invited. Whilst non-standard submissions are welcome, there may be additional time associated with their publication.

Discussion

A move to electronic publication is welcome but there are some reservations as to whether people would be aware that interesting articles had been published without the hard-copy journal arriving by post. It is likely that this issue will be addressed by delivering tables of content for issues by email to subscribers. Members of the Society for Radiological Protection (SRP) will automatically have access to the JRP when logging onto the members site of the SRP website.

5.4 TOPICS OF POTENTIAL INTEREST FOR COLLABORATIVE BIOPROTA WORKSHOPS AND/OR PROJECTS

Potential topics of interest were discussed and are summarised below. These include ideas raised during previous BIOPROTA meetings that were revisited in discussions as well as additional topics also identified as a result of the presentations and associated discussions during the meeting. A poll will be organised following the meeting that includes a long list of all topics identified to gauge the level of interest across member organisations in the workshop/project ideas being taken forward. Additional ideas for topics are invited. Where there is sufficient interest for a topic, members are invited to develop proposals for workshops and/or projects and the BIOPROTA Technical Secretariat can support development as required.

Screening approaches and key contaminants, including radon and polonium

Screening approaches to identifying the contaminants of interest have been presented by FANC and NWMO and it is recognised that this is an area of interest for other member organisations. There may, therefore, be merit in sharing experience around the development and application of screening approaches during a topical workshop.

Workshops could be organised around key contaminants of interest. As discussed previously, this could be to consider new contaminants of interest or to revisit those previously considered in BIOPROTA work programmes.

Radon was identified as an issue in the recent update to the ERICA assessment tool. Previously, when radon inhalation was not explicitly considered in ERICA, dose rates associated with parent radionuclides (e.g., Th-226 and Ra-226) in soils were not of concern (based on unit activity concentrations). However, the inclusion of radon (and thoron) inhalation in the beta test version of ERICA version 2.0 resulted in the ERICA screening value being exceeded for the same unit input of the parent radionuclide due to the assumptions applied in deriving activity concentrations in soil gas and its emanation to above-ground atmosphere. Radon is also of interest for human dose assessments and there may, therefore, be interest in looking at the ways in which radon generated in soils is accounted for in different assessments.

Polonium has also been identified as a radionuclide of concern for SKB with data relating to its behaviour being difficult to locate. This is also the case for other radionuclides in the complex uranium decay series, including radon as noted above. This highlights the importance of teasing out progeny in decay series when looking at radionuclides of interest. In some instances, it may be progeny that are an issue and these may be missed during screening exercises. The uranium decay series has been considered previously within BIOPROTA, but with polonium and radon being identified as of particular interest, it may be timely to revisit through a topical workshop.

Assessing radionuclides and non-radioactive contaminants proportionately

There have been a series of work programmes on this topic, including topical workshops and focussed projects and interest remains around this topic. This is further considered in Section 5.2. It is worth noting that there may be interest in considering not just impacts on people from radioactive and non-radioactive contaminants, but also on the environment.

Stakeholder involvement in biosphere studies

On the side of the operator, this would involve engagement with the potentially affected community to help ensure stakeholder concerns are reflected in biosphere studies. From the side of the regulator, this may include engagement with communities, including education and communicating on risks associated with contaminants in the environment, which can be a challenging issue. The sharing of experience in planning and engaging with a range of different stakeholders and lessons learned could be very beneficial, noting that engagement with stakeholders can lead to new endpoints of interest being identified (e.g. doses to people with modern lifestyles in addition to exposure groups based on self-sufficient lifestyles). There may be merit in also engaging with those responsible for addressing legacy site issues, where there can be similar experience and interests and relevant lessons learned with respect to engaging with stakeholders.

Bioavailable soil-plant concentration ratios

This topic was presented previously as an idea for a topical workshop by Lauri Parviainen (Posiva) and continues to be a topic of interest. Concentration ratios are based on an assumption of equilibrium concentrations in both the plant (or animal) of interest and the surrounding environmental media (e.g. soil). The data upon which ratios are calculated are key and may not always represent the bioavailable fraction, which may introduce errors and pessimisms to assessment models. For example, ratios based on stable element analyses are often applied to trace concentrations of radionuclides and there may be merit in considering whether this extrapolation is appropriate. A workshop around this topic could help in refining the way analyses are undertaken in site programmes and/or identify other ways in which uncertainties may be addressed.

Comparison of biosphere modelling approaches and supporting assessment models

Comparison of biosphere modelling approaches could include specific elements of models or pathways to identify approaches taken in different projects or comparison of modelling approaches more broadly through, for example, comparing biosphere dose factors. The topic is also linked to bioavailable soil-plant concentration ratios (above) and there may, therefore, be merit in combining both subjects within a wider topical workshop.

Detailed models are commonly applied to consider particular aspects of interest in assessments, such as groundwater discharge and recharge on small spatial scales (e.g. hyporheic flows) or to model the transport of radionuclides with complex behaviours to and within the surface environment with those models then providing input to broader assessment models. A topical workshop would enable the application of different modelling codes and tools to be presented and discussed in terms of good practise, reporting and quality assurance. Many aspects of assessment modelling can be considered as ‘simple’ but when the various aspects are combined this can become very complex and it can be a challenge to maintain version control etc. This could therefore provide a useful opportunity to share lessons learned within the assessment community, including identifying the limits and constraints associated with the application of different models and development of advice around when more complex dynamic models can be used to build confidence around more simple models and the extraction of information as input to assessment models.

If a workshop were to be organised around this topic, there may be merit in summarising previous BIOPROTA work programmes that have focussed on particular processes and/or radionuclides (e.g. Cl-36 and Se-79 etc.) to ensure participants are aware of the information available from these programmes.

In terms of model validation, it was noted that there could be benefit, particularly for those new to biosphere modelling, to develop some benchmark scenarios that could be applied both in terms of training and skills development for individuals but also as a means of validating and building confidence in components of models or to check that all relevant processes are included in models. The comparison of different models can also help in identifying safety margins.

Spatial scales for environmental protection

This topic relates to spatial scales considered for human dose assessments and how to integrate those with spatial scales that may be required for the protection of populations of non-human biota, building upon the BIOPROTA SPACE project (see also discussion in Section 2.12). The idea would be to develop more precise and clear ideas around what is meant by environmental protection and scales of interest (i.e. the size of a population and the area needed to sustain that population). The objective would be to ensure that assessments aren't grossly disproportionate by focussing on defining the protection target (a population of interest) and evaluating exposures commensurate with that target. The topic is also of interest with respect to landscape and climate evolution in long-term assessments and how to represent biota populations. Several documented assessments are now available that could be discussed.

Workshop on site characterisation and integrating site understanding

RWM currently have a project underway to develop a roadmap for site characterisation which can be shared once the project report has been finalised. How to integrate site understanding is a topic of particular interest and the sharing of information on this topic may be very beneficial for those moving from generic to site-specific assessments.

6. FORUM ARRANGEMENTS FOR 2022

6.1 FEEDBACK FROM THE 2021 SPONSORING COMMITTEE MEETING

Alex Diener (BfS and BIOPROTA chair) presented feedback from a Sponsoring Committee meeting that took place during the course of the annual meeting. Key points, including actions agreed in discussion of the feedback are summarised below.

The BIOPROTA arrangements for 2021 were reviewed, including the policy for membership of the forum, and there were no objections/suggestions for improvement from members.

The current membership stands at 23 full members and here were 4 existing academic members. UEF was accepted and welcomed as a new (fifth) academic member.

Previous organisations that were members but whose membership has ended include Ciemat (Spain), Orano (France) and EPRI (USA). Reasons for membership ending include funding availability and changes in interest areas (e.g. the halt in the Yucca Mountain project in the USA). All organisations are welcome to re-join should they wish and contact will be maintained. New organisations are also welcome; BGE in Germany has recently expressed interest and has been passed the appropriate contact information.

Development of a priority list of potential topics for collaborative work would be welcomed. This could be achieved through the development of a poll around the long-list of potential topics of interest (as discussed in Section 5.4). The distribution of a poll following the meeting will help remind members to consider the potential topics and gauge interest levels.

It is hoped that face-to-face meetings will begin again in 2022, potentially with an extended meeting to celebrate 20 years of BIOPROTA and reflect on achievements. There is also the potential to continue with web-based meetings, potentially with a web-based meeting being held each year in the autumn in addition to a face-to-face meeting around May; members agreed this would be a good idea because the web-hosted meetings helped facilitate wider participation. Consideration could also be given to arranging a hybrid annual meeting, but this will depend on host organisations having the facilities to support such meetings. Alternatively small update sessions could be held online toward the end of face-to-face meetings to provide an opportunity for wider engagement and feedback on topics identified as potentially of interest.

A numbering system for BIOPROTA reports has been discussed previously and still needs to be implemented. The need to register on the forum website in order to gain access to workshop and project reports has been removed, but may be reinstated for access to annual meeting reports so that access is restricted to members only.

Prior to the next annual meeting, it would be useful to draft a list of tasks that are expected of the forum chairperson to inform those that may be interested in taking on the role, noting there is no requirement for a chairperson to also provide facilities to host the annual meetings as it is recognised that the availability of suitable facilities varies across member organisations. The tasks will be drafted and added to the annual arrangements document that is distributed on an annual basis. Further information on forum funding would also be useful to improve transparency.

6.2 FORUM ARRANGEMENTS FOR 2022

Assuming face-to-face meetings are possible in 2022, the next annual meeting will be organised for May (or possibly June). Andra has kindly offered to host the meeting in Paris unless Surao, as the intended host for the 2020 meeting which had to be cancelled due to pandemic, would be interested in hosting.

2021 marked 20 years of BIOPROTA and the intention had been to hold an extended annual meeting to mark the occasion but, due to the ongoing pandemic, this was not possible. The suggestion was made, therefore, that the 2022 meeting be extended (assuming in-person meetings are possible). This would provide an opportunity to go into greater detail in particular topics of interest (e.g. through topical sessions). It could be interesting to invite all members to consider presentations, providing a retrospective look at their biosphere programmes, and to reflect on what has worked well and how models and assessments have developed and improved over time. It was noted that, if a celebratory 20-year meeting were to be arranged, this could be mentioned along with background to BIOPROTA in an article for the JRP to promote the forum and its activities more widely.

As mentioned in the Sponsoring Committee feedback, it is intended that an autumn on-line meeting will also be organised. If there remains uncertainty around travel, it may be necessary to switch to an on-line spring meeting followed by an autumn face-to-face meeting. The situation will continue to be monitored and arrangements kept flexible.

APPENDIX A. 2021 MEETING PARTICIPANTS

Participant	Organisation	Country
Yves Thiry	Andra	France
Špela Mechora	ARAO	Slovenia
Alex Diener	BfS	Germany
Ian Barraclough	DSA	Norway
Jelena Popic	DSA	Norway
Laura Milelli	EDF	France
Taku Tanaka	EDF	France
Philipp Schädle	ENSI	Switzerland
Ari Ikonen	EnviroCase & SKB TSO	Finland
Dan Schultheisz	EPA	USA
David Stuenkel	EPA	USA
Eugenio-Felipe Santillan	EPA	USA
Jay Santillan	EPA	USA
Jon Major	EPA	USA
Mike Boyd	EPA	USA
Tom Peake	EPA	USA
Xinyue Tong	EPA	USA
Maryna Surkova	FANC	Belgium
Graham Smith	GMS Abingdon & Clemson University	UK
Leona Higashi	JANUS	Japan
Tomomi Ito	JANUS	Japan
Yukiko Fukaya	JANUS	Japan
Jongtae Jeong	KAERI	Republic of Korea
Jung-Woo Kim	KAERI	Republic of Korea
Minjeong Kim	KAERI	Republic of Korea
James Ridehalgh	LLWR	UK
Mike Thorne	Mike Thorne and Associates	UK
Keisuke Ishida	NUMO	Japan
Antoine Boyer	NWMO	Canada
Chantal Medri	NWMO	Canada
Joanne Jacyk	NWMO	Canada
Mark Gobien	NWMO	Canada
Mihaela Ion	NWMO	Canada
Lauri Parviainen	Posiva	Finland
Russell Walke	Quintessa & BIOPROTA Technical Secretariat	UK
Laura Limer	Quintessa (MS Teams meeting administrator)	UK
Karen Smith	RadEcol Consulting & BIOPROTA Technical Secretariat	UK
Kat Raines	RWM	UK
Ray Kowe	RWM	UK
Jordi Vives	SCK·CEN	Belgium

Sari Peura	SKB	Sweden
Ulrik Kautsky	SKB	Sweden
Maria Nordén	SSM	Sweden
Dmitry Lukin	SURAO	Czech Republic
Christina Biasi	University of Eastern Finland	Finland
Pinja Jyllilä	University of Eastern Finland	Finland
Soroush Majlesi	University of Eastern Finland	Finland