BIOPROTA

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

Report of the 2019 BIOPROTA Annual Meeting

Munich, Germany
13-14 May 2019

Version 2.0, Final
2 October 2019

PREFACE

BIOPROTA is an international collaborative forum that seeks to address key uncertainties in the assessment of environmental and human health impacts in the long-term arising from release of radionuclides and other contaminants as a result of radioactive waste management practices. It is understood that there are radioecological and other data and information issues that are common to assessments required in many countries. 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 radiological and related assessments of radioactive waste management.

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 2019 BIOPROTA annual meeting. The meeting was hosted by BfS in Munich, Germany, from 13th to 14th May 2019. 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 6 August 2019.

Version 2.0: Final report prepared by Karen Smith (RadEcol Consulting Ltd) based on participant comments arising from review of version 1.0. Distributed to meeting participants and forum members 2 October 2019.

CONTENTS

1. INTRODUCTION

The 2019 BIOPROTA annual meeting was hosted by Bundesamt für Strahlenschutz (BfS) in Munich, Germany from 13th to 14th May, and began with a short introduction to BfS from Martin Steiner. BfS was established in 1989, partly as a consequence of the Chernobyl accident, with the remit of pooling competencies in the area of radiation protection, inclusive of environmental protection, emergency preparedness, medical and occupational radiation protection and the effects and risks of ionising radiation and non-ionising radiation. In 2016 the organisation was split into three, to avoid BfS being both the operator and regulator for radioactive waste disposal sites, resulting in the following organisations:

- Bundesamt für Strahlenschutz (BfS) – responsible for federal tasks of radiation protection;
- Bundesgesellschaft für Endlagerung (BGE) – the operator for radioactive waste disposal projects; and,
- Bundesamt für kerntechnische Entsorgungssicherheit (BfE) – the licensing authority for interim storage facilities, nuclear transport and radioactive waste disposals.

BfS consists of two large departments covering radiation protection and the environment and radiation protection and health. Each department has two sub-divisions. A biosphere modelling unit sits within the environmental radioactivity sub-division. Particular topics of interest for the unit are the dynamic behaviour of radionuclides, improved radioecology models, and general administrative regulations for biosphere modelling. Further information on BfS is available from the website www.bfs.de.

The support of BfS in the organisation and hosting of the 2019 annual BIOPROTA meeting is gratefully acknowledged.

1.1 OVERVIEW OF THE BIOPROTA FORUM AND OBJECTIVES OF THE ANNUAL MEETING

The international BIOPROTA forum was set up in 2002. The forum aims to provide a flexible and independent platform for discussing and addressing common issues in biosphere assessments that is complementary to other projects/programmes, such as those run by the IAEA. The scope of the forum is defined in the BIOPROTA Arrangements document that is updated annually and distributed to all members. This is a key document for the forum, setting out how the forum works administratively and providing an overview of the work programme.

Membership of the forum is aimed at national authorities, agencies and other organisations, including technical support organisations and independent research institutions, with responsibilities and interests related to achieving safe and acceptable radioactive waste management. There are currently two grades of membership. Full members pay a membership fee, to support the role of the technical secretariat, and 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. Sponsoring members in 2018 were as follows:

- ANDRA, France
- ARAO, Slovenia
- NAGRA, Switzerland
- NUMO, Japan

- BfS, Germany
- DSA (formerly NRPA), Norway
- EDF, France
- ENSI, Switzerland
- FANC, Belgium
- IRSN, France
- JGC Corporation, Japan
- KAERI, Korea
- KORAD, Korea
- LLWR, UK
- NWMO, Canada
- Orano (formerly AREVA), France
- POSIVA, Finland
- RWM, UK
- SCK·CEN, Belgium
- SKB, Sweden
- SSM, Sweden
- SURAO, Czech Republic
- UJV, Czech Republic

The academic members in 2018 were:

- Oregon State University, USA
- Clemson University, USA
- University of Life Sciences, Norway

At the time of the 2019 annual meeting, membership invitations had been distributed to all current members. In addition, the US EPA is welcomed as a new member. Nottingham University in the UK had also been invited as a potential new academic member.

The objectives of the BIOPROTA forum are:

- to provide a forum for exchange of information to support the resolution of key issues in biosphere aspects of assessments of the long-term impact of contaminant releases associated with radioactive waste disposal and contaminated land management; and,
- to make available the best sources of information to justify modelling assumptions made within long-term radiological assessments.

The structure of the forum is illustrated in Figure 1. The Sponsoring Committee is headed by a chairperson who is elected each year during the annual BIOPROTA meeting. The chairperson in 2018 was Alexander Diener from BfS.

A general meeting of the BIOPROTA forum meeting is held each year. In addition, topical workshops and projects are undertaken, driven by needs and interests of member organisations, as identified and discussed during the annual meetings. It is, therefore, the members of the forum that drive the work programme with a technical secretariat providing support, as required. Project and topical workshop reports, along with annual meeting reports, are made available on the forum website (www.bioprota.org) following review and approval by sponsors and participants. Reports may also be published within the reports series of one of the sponsoring organisations.

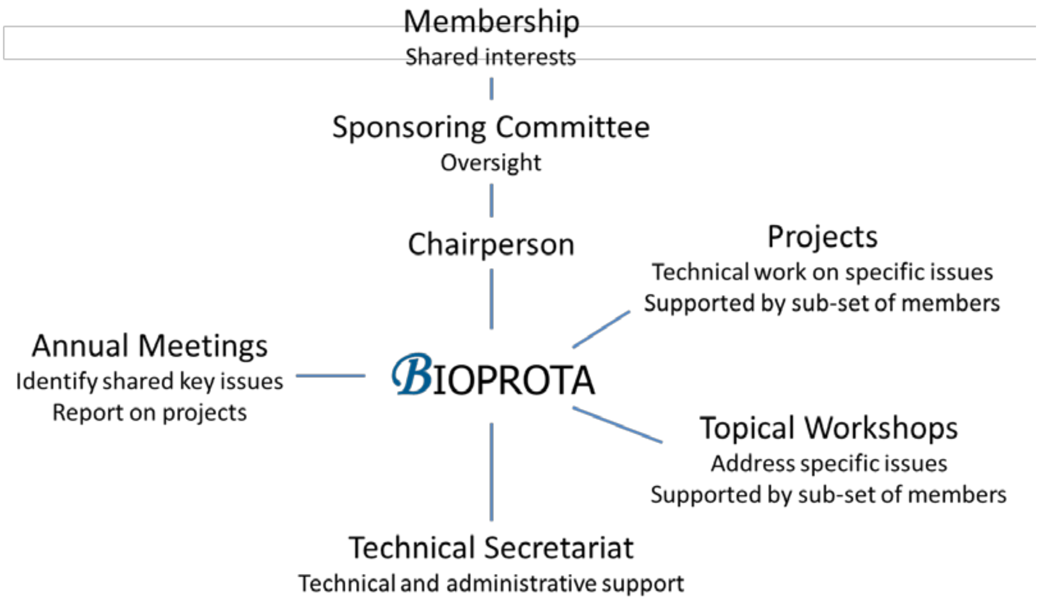

Figure 1. Structure of the BIOPROTA forum.

The annual meetings provide an opportunity for members to discuss their biosphere programmes, for progress on BIOPROTA work programmes to be reported, and for new collaborative tasks to be identified around common issues. However, suggestions and proposals for projects and topical workshops can be submitted at any time. Proposals, to include estimates of time and cost, are distributed by the technical secretariat to invite organisations with similar interests to provide financial support (and/or technical support, as appropriate). Where there is sufficient support, the work programme progresses. Those organisations supporting a project are engaged in the way in which the project is run, by being invited to form a project sponsoring committee. Following completion of the project, and with the agreement of the project sponsors, the output is then shared more widely. To date, over thirty project and workshop reports have been produced.

The 2019 annual meeting was structured to support the exchange of information and experience relating to biosphere assessment programmes and the output of BIOPROTA projects since the 2018 annual meeting, and to identify and discuss ideas for future collaborative projects. The following sessions were held:

- Session 1: Progress and perspectives for the future from member organisations.
- Session 2: Radionuclides of special interest.
- Session 3: Current work programmes and future projects.
- Session 4: Summary and forum arrangements for 2019/20.

1.2 PARTICIPATION

The meeting was attended by 30 participants from 10 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 then summarises the topical session on radionuclides of special interest. An overview of current BIOPROTA work activities and possible future projects is then provided in Section 4, with forum arrangements in 2019-20 being detailed in Section 5.

2. PROGRESS AND PERSPECTIVES FOR THE FUTURE FROM MEMBER ORGANISATIONS

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

2.1 OVERVIEW OF THE SELECTION OF THE HLW REPOSITORY IN GERMANY

Alexander Diener (BfS) presented.

Current locations of repositories for radioactive waste in Germany are illustrated in Figure 2.

Figure 2. Repository locations in Germany.

Konrad was the first repository licensed under nuclear law in Germany with permission for its construction being granted in 2007. It is a former iron ore mine, located in Lower Saxony, that is now being converted into a repository for the permanent storage of up to 303,000 m^3 of radioactive waste with negligible heat generation. The repository is due to receive wastes for permanent storage from 2027.

The Morsleben repository is located in Saxony-Anhalt and was subject to permanent storage of around 37,000 m^3 of low and intermediate level waste (L/ILW) with negligible heat generation between 1971 and 1991 and from 1994 to 1998. Morsleben is a former salt mine that does not meet current criteria for a repository but can be safely closed in accordance with current legal regulations. An application to legally close the facility has been submitted.

Asse II is a former potash and salt mine in lower Saxony that was used to test the handling and storage of radioactive waste in a repository between 1967 and 1978; 47,000 m^3 of L/ILW was stored in the mine. The mine currently faces two major problems: (i) saline solutions are entering the mine, and (ii) instability of the mine opening. There has been a regulatory requirement to retrieve the waste and decommission the mine since 2013, so long as the mine is considered stable enough for work to be undertaken and radiological risks to workers remain within authorised limits.

The Gorleben mine site was explored between 1977 and 2000 and then from 2010 to 2013 to investigate the suitability of the salt dome as a potential repository for high level waste (HLW). The decision to investigate the site as a possible repository location has, however, been criticised as being politically driven and without transparency or a comprehensive site selection process. As such, since 2013, the site has been given equal status to any other potential site in Germany and the facility has been partially decommissioned.

The procedure for selection of a site for the safe storage of HLW in Germany is defined in the 2013 Site Selection Act. The objective is to identify a site that will offer the best safety over a 1 million year period. The process is required to be transparent and to be undertaken in four steps (with sub-steps as required) with the regulator deciding on the procedure for each step following completion of the prior step. The stepwise procedure is as follows:

- Step 1: Determination of sub-areas in Germany;
- Step 1: Determination of regions for surface exploration;
- Step 2: Decision on surface exploration and exploratory programmes;
- Step 2: Surface exploration and proposal for subsurface exploration;
- Step 3: Decision on subsurface exploration and exploratory programmes;
- Step 3: Subsurface exploration;
- Step 3: Final comparison of sites and proposal of a site; and,
- Step 4: Decision for a site.

Several exclusion criteria are set by the law:

- the repository host rock must be either salt rock, clay rock or crystalline basement;
- the vertical movement within the repository must be less than 1 mm per year on average;
- there can be no fault zones or volcanic activity present and only limited seismic activity;
- there can be no present or past impact from mining; and,
- there should be no exploitable fresh groundwater in the waste storage area of the host rock.

Minimum requirements are also set, focussing on the effective containment zone. For example, the thickness of the zone must be at least 100 m, the distance between the containment zone and the surface should be at least 300 m and the multi-barrier system is to remain effective for 1 million years.

Each potential site is required to be investigated on the basis of geoscientific consideration criteria to analyse the geological situation and its usability as a HLW repository. Example criteria for the transport of radioactive contaminants by groundwater in the containment zone are provided in Table 1.

Table 1. Criteria for the evaluation of transport of radioactive contaminants by groundwater flow in the effective containment zone.

Evaluated property	Evaluated quantity	Evaluation group		
		favourable	partly favourable	unfavourable
Groundwater flow	Groundwater flow velocity [mm/a]	< 0.1	0.1 – 1	> 1
Groundwater availability	Permeability of host rocks [m/s]	$< 10^{-12}$	$10^{-12} – 10^{-10}$	$> 10^{-10}$
Diffusion speed	Effective diffusion coefficient of the host rock for tritiated water [m^2/s]	$< 10^{-11}$	$10^{-11} – 10^{-10}$	$> 10^{-10}$
Diffusion speed in clay rock	Porosity	< 20 %	20 % – 40 %	> 40 %
	Degree of solidification	Clay rock	Solid clay	Semi-solid clay

The Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) has overall political responsibility for the site selection process and supervises the operator BGE that is required to apply the multi-step site selection procedure. BfE has regulatory responsibility and assesses the proposals of BGE and organises stakeholder engagement. Various stakeholders, including members of the public, representatives of organisations, scientists and members of regional authorities, can participate in the site selection process within regional and supra-regional frameworks. A National Civil Society Board will provide independent scrutiny of the site selection process.

The current aim is to have selected a site for the permanent storage of HLW by 2031 with Step 1 of the selection process having already begun with the BGE investigating geological and hydrogeological maps. Further regulations need to be developed that will specify the operator's tasks and the detailed repository requirements, including a regulation on how to calculate the migration of the radionuclides from the near-field to the biosphere and how to calculate dose to a representative person.

Discussion

The decommissioning of the Asse II mine is being funded through the Ministry for the Environment and is, therefore, funded by taxpayers. The inventory disposed to the mine is known. Members of the public are strongly opposed to the mine and there is a clear need to correct the issues. The law addressing the management of the mine requires all wastes should be brought to the surface. This is an ambitious target and there are doubts as to whether full retrieval and reconditioning of wastes will be achievable.

2.2 BIOSPHERE ASSESSMENT: LESSONS LEARNED IN BELGIUM

Maryna Surkova (FANC) presented.

The Federal Agency for Nuclear Control (FANC) is the Belgian regulatory body for nuclear safety. The National Agency for Radioactive Waste and enriched Fissile Material (ONDRAF/NIRAS) is the national waste management organisation responsible for the management and disposal of radioactive wastes. The presentation was focussed on lessons learned around a license application for the surface disposal of around 163,000 m^3 'Category A' waste (short-lived low and intermediate level wastes) in 34 above-ground disposal modules in the municipality of Dessel.

The license application dossier was submitted by ONDRAF/NIRAS in 2013. Six months later the dossier was deemed incomplete by FANC and a list of 300 questions was developed that were addressed by ONDRAF/NIRAS by December 2017. In February 2019, ONDRAF/NIRAS submitted an updated safety case.

The disposal facility will consist of 34 fixed-roof disposal modules. Wastes will be delivered to the facility via the Bocholg-Herentals canal with a dedicated loading/unloading quay constructed. Wastes will be contained in concrete boxes (caissons) with 12 cm thick walls. The boxes will contain either standard drums of waste (5 x 200 litre or 4 x 400 litre), single non-standard waste drums or bulk waste from the decommissioning of nuclear installations. The caissons, once filled with wastes, will be sealed and filled with mortar prior to being disposed of in the modules. The walls of the modules will consist of 70 cm thick reinforced concrete that can withstand earthquakes. The modules will be constructed in two phases. The first phase will involve the construction of 20 modules. The remaining 14 modules will be constructed during the second phase. A communication centre will be built for public engagement. A demonstration module has been constructed.

2.2.1 Regulatory framework

General regulations for the protection of people and the environment from ionising radiation are set by the Royal Decree of 20 July 2001. Safety requirements for nuclear installations are set by the Royal Decree of 30 November 2011, which includes specific safety regulations for facilities for the final disposal of radioactive wastes. International guidance from the IAEA must also be taken into account when developing a disposal safety case, along with Belgian guidance documents on the treatment of the biosphere in safety assessments, including:

- guidance on surface disposal on Belgian territory of low and intermediate short-lived waste;
- strategic note and guidelines on license applications;
- guidance on consideration of human intrusion at surface disposal facilities for radioactive waste;
- guidance on the consideration of events of external origin in the design of the disposal facility;
- guidance on "Earthquakes";
- guidance on "Safety evaluation: aspects related to groundwater";
- guidance on "Safety evaluation: biosphere";
- guidance on "Radiation protection criteria (RPC-LT) for the long-term safety evaluation of a surface disposal facility for radioactive waste";

- guidance on radiation protection during the operational period of a surface disposal facility for radioactive waste; and

- note "Acceptability of potential exposures due to internal and external events and concerning disposal facilities for radioactive waste".

A dose constraint of 0.1 mSv/y is applied for an assessment timeframe in which dose calculations could be considered sufficiently reliable. After this time the same value is used as a reference value. Drinking water protection standards are also applied to meet the objective of ensuring a repository will not cause restrictions in water use for human consumption or generate excessive constraints for future generations.

2.2.2 Biosphere assessment conceptual model

The primary quantitative safety indicator for assessing the radiological impact of disposal is the dose to a representative person. For the expected evolution scenario, dose to a representative person is calculated in three steps. Initially the infiltration of water through the near-field is determined to give the radionuclide flux due to leaching. Hydrogeological modelling is then undertaken to calculate groundwater flow and the transport of radionuclides to derive geosphere transfer factors (Bq/m^3)/(Bq/y). Biosphere dose conversion factors are then applied to calculate the impact (annual dose rate) for a representative person. The biosphere dose conversion factors are largely derived on the basis of best estimate values for assessment parameters.

The biosphere modelling approach is based around reference biospheres; i.e. a stylised model of the biosphere is used in a safety assessment with various components such as climate, fauna, flora and hydrology being specified. The stylisation involves a set of assumptions around the evolution of the facility and the biosphere over time and with regards to the site-specific nature of the assessment. Present-day habits are assumed with the representative person being part of a self-sustaining farming community. Three age groups (adult, child and infant) are considered. The farming community is assumed to be located in the area of maximum potential contamination of biosphere components and spend a large proportion of time on potentially contaminated fields/pasture. They are assumed to consume the same average diet as other local residents and to fish in potentially contaminated water bodies (if present). It is cautiously assumed that any consumption of well water occurs without pre-treatment.

The main biosphere receptor components considered were a private well, a river and wetlands.

2.2.3 Lessons learned

There were several lessons learned as a result of the regulatory review of the biosphere assessment.

- In the case of a wetland biosphere receptor, an agricultural community was assumed to extract drinking water from a well in shallow groundwater, but agricultural animals were not assumed to consume this water. This pathway was subsequently required to be addressed following regulatory review. Furthermore, lakes and river sediments were not considered from the beginning of the assessment programme and had to be taken into account at later stages. Lesson learned: identify and agree upon all biosphere receptors at the outset.

- Initially, only the present-day temperate climate conditions were considered, but this was not deemed sufficient. Subsequently, constant reference biospheres around each of three climate scenarios for agricultural land use were considered, based on the expected climate evolution for the next 2000 years[a] for which a subtropical climate is expected for the entire period relevant to long-term safety assessment following closure of the facility. The use of climate scenarios illustrated the need to adapt hypotheses and parameters that were important for the biosphere assessment, such as assumptions around irrigation rates. Lesson learned: future climate consequences on the biosphere need to be considered before fixing the biosphere model in terms of hypotheses and parameters.

- Three principal types of scenario were considered in the initial assessment – an expected evolution scenario, alternative evolution scenarios and human intrusion scenarios. Additional scenarios were defined for use in specific assessment calculations, such as screening scenarios for determination of critical radionuclides. An additional penalising scenario was, however, required to be assessed that assumed complete failure of the system after 2,000 years. Furthermore, for human intrusion scenarios, the impact assessment had focussed on the impacts to those intruding into the facility whereas the impacts on neighbouring areas were also required to be evaluated. Lesson learned: the development and assessment of the penalising scenario and consideration of delayed exposure of neighbouring populations following human intrusion were required.

- Uncertainties around the performance of the disposal system increase over timescales of several thousand years and geological processes and extreme events become less predictable over time. Although a hypothetical and stylised biosphere approach is taken, sensitivity analysis is required to identify the main controlling parameters and assumptions and to identify the uncertainties around them during the biosphere model development process. Lesson learned: it is important to develop at the outset a strategy for handling uncertainties in the biosphere model.

Discussion

Wastes are currently stored in bunkers that appear similar to those that will be used for final disposal, but do not have the level of engineering that disposal bunkers will have. The disposal bunkers will be around 11 m in height and are expected to have a lifetime of 350 years. The main uncertainty for disposal of Category A wastes is the waste inventory. Despite a range of proposals, there is currently no facility for disposal of long-lived ILW or HLW in Belgium.

Criticism around the way in which uncertainties had been handled in the assessment was largely that sensitivity and uncertainty analyses had not been performed in all instances and justification for assumptions etc. was not always given.

2.3 BSA-2020: BIOSPHERE ASSESSMENT FOR THE SAFETY CASE OF THE OPERATIONAL LICENCE APPLICATION IN FINLAND

Lauri Parviainen (Posiva) presented.

A construction licence was granted in 2015 for a repository for spent nuclear fuel at Olkiluoto in southwest Finland. Construction of the facility is underway with excavations of repository tunnels

[a] Climate change impact on hydrological extremes along rivers and urban drainage systems in Belgium. See https://www.kuleuven.be/hydr/cci/reports/CCI-HYDR_FinalReport.pdf.

having commenced, along with excavation works for an encapsulation plant. Commissioning of the disposal facility is planned for 2024.

A full-scale in situ system test is being undertaken. This has involved emplacement of full-scale canisters in disposal positions with bentonite backfill. The canisters have heaters inside them and various measurements will be taken, including temperature and pressure.

The reference design for the back filling of disposal tunnels was for bentonite blocks to be used. This has recently been revised to the use of bentonite pellets that will allow for more rapid back filling of tunnels as well as being more effective in filling the overall space.

Work is also underway on the performance assessment (TURVA-2020) that will underpin the operational licence application. The TURVA-2020 report portfolio consists of the following:

- Initial State report – initial state of the repository system and present conditions of the surface environment;
- Olkiluoto Site Description report;
- Performance Assessment and Formulation of Scenarios (PAFOS) report – assessment relative to performance targets, taking into account the expected and alternative climate and surface environment evolutions, with scenarios being formulated around uncertainties/deviations identified in the assessment;
- Models and Data report – detailing the assessment models and data management approach for the performance assessment and analysis of releases;
- Analysis of Releases (AOR) report – providing an overview of the main results from the radionuclide release and transport modelling from the repository system to the surface environment and evaluation of radiological consequences; and
- Complementary Considerations report – providing supporting evidence for safety, including natural and anthropogenic analogues.

Reporting is supported by a web-based content management system (CMS) that includes the database of features, event and processes (FEPs) and the database of all safety assessment parameters. All safety assessment reports will be included in the CMS. Consistent with the 2012 construction licence assessment, the main biosphere reports include:

- terrain and ecosystems development modelling, describing how the site might develop over time and forming the basis for the landscape model;
- surface and near-surface hydrological modelling;
- radionuclide transport and dose modelling;
- non-human biota dose assessment; and,
- surface environment data and description reports (sorption processes, fauna, agriculture, aquatic environment, and forests and mires), which cover the following topics:

- development of the ‘biotope’;
- description of biotopes and typology;
- FEPs and conceptual models;
- materials and methods of field studies;
- results of field studies;
- data handling and derivation of parameter values;
- the parameter values; and
- uncertainties.

The biosphere modelling area is much larger than the release area from the geosphere.

Groundwater and surface hydrological models will be coupled. Together, these will help to identify and characterise the landscape objects that might receive contamination (high water transmission areas will give rise to potential releases to biosphere objects that will then be further transported through the surface system).

The radionuclide transport and dose model consists of a range of interlinked biosphere objects, each with structured components as illustrated in Figure 3.

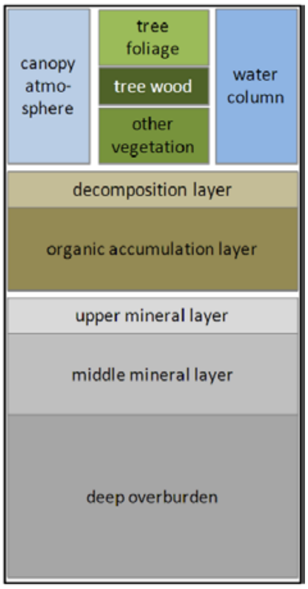

Figure 3. Components of biosphere objects reflected in radionuclide transport and dose modelling.

The main drivers for calculation cases are climate scenarios (temperate, prolonged temperate and early periglacial with permafrost occurring within the first 20,000 years post-closure) and analysis of potential releases. The prolonged temperate climate scenario involves the repository location being submerged as a result of increased sea level. Biosphere assessment is not so important in this case, but the scenario is important for the repository itself. Various assumptions around discharge locations, sedimentation rates and human habits are being considered through the range of calculation cases, which explore alternative assumptions.

Assessment models are due to be finalised by the end of 2019. Parameter values that will be used in the assessments are currently being reviewed and will also be finalised by the end of 2019. Transport and dose calculations will then proceed in 2020 with report finalisation and review being undertaken in 2021, ready for submission of the operational licence application by the end of that year.

Discussion

The connection between groundwater and surface hydrology is based around water fluxes. The release locations are based on geological investigations and will not change over time. Time development is, however, evaluated with regards to the source term.

With shoreline displacement, there will be variation in whether freshwater or brackish water infiltrates the repository.

The assessment of impacts on non-human biota is based around the ERICA assessment approach, with representative species being evaluated relative to radionuclide concentrations calculated for different environmental media.

2.4 LEGAL FRAME OF THE ADMINISTRATIVE REGULATION TO BE USED FOR DOSE CALCULATIONS AFTER POTENTIAL RELEASES OF RADIONUCLIDES FROM THE HLW REPOSITORY IN GERMANY

Alexander Diener (BfS) presented.

Regulations for evaluating the exposure of the representative person from radionuclide releases from a HLW repository in Germany are being developed. Evaluation of radionuclide transport in the host rock is being considered by BfE and BfS is responsible for developing the biosphere modelling and dose calculation aspects. No regulations currently exist with regard to exposure assessment for the HLW repository. The first step is to define the geosphere-biosphere interface (GBI)to avoid gaps when modelling the radionuclide migration from the geosphere into the biosphere. Once this is defined, the statutory requirements and demands for repository safety must be identified and consensus reached between BMU, BfS and BfE on assumptions.

Radioactivity concentrations at the GBI are the input for biosphere modelling. Required data include groundwater flow rate from the geosphere to the biosphere and concentrations of radionuclides, non-radioactive pollutants and dissolved salts in the aquifers. For gaseous radionuclide transport, the GBI is taken to be the boundary between solid rocks and soils. For water-mediated transport of radionuclides, the GBI is any groundwater body that migrates into surface waters and/or are located close to the surface such that they could be used for irrigation or drinking water for people and/or livestock.

Four GBI's are considered through different scenarios:

- a well scenario considers the use of contaminated aquifers for water extraction;
- a spring scenario considers the inflow of groundwater to limnic systems;

- an ascending gas scenario considers the gaseous transport of radionuclides from host rock into the biosphere; and
- a rising groundwater scenario considers seasonal groundwater rise resulting from inflow of water from saturated aquifers and precipitation within the catchment.

It is the role of BfE to suggest the statutory requirements to BMU regarding water-bound transport of radionuclides through the host rock, inflow into groundwater, the water chemistry of the inflow into groundwater and the transport of radionuclides in the gaseous phase through host rocks to the uppermost rock layer. It is then BfS that suggests the statutory requirements for:

- mixing of the contaminated inflow from host rocks into groundwater;
- groundwater balance model;
- advective groundwater flow and groundwater transport;
- rising groundwater due to inflow of water from saturated aquifers and precipitation within the catchment area;
- gaseous transport into soils, surface waters, atmosphere;
- mixing of contaminated groundwater with surface water;
- transport of radionuclides in surface waters;
- extraction and use of water by humans and uptake by roots; and,
- dose calculations of the public.

The legal requirements are the framework within which administrative regulations are to be prepared. The biosphere is taken to be the surface environment, inclusive of near-surface groundwater. It is not considered part of the repository system but does place requirements on the repository system with regards to effective containment. The timeframe for safety evaluation for HLW is 1 million years post-closure.

In terms of the site-selection process, no dose calculations are required during Step 1. During Step 2, generic transport and dose calculations are required, with more detailed site-specific assessments being undertaken during Step 3. Evaluation of exposure for members of the public is based on a representative person with present-day living habits and sustainable agricultural practices being assumed.

Protection of the environment is a legal requirement and the approach to be taken is still under discussion, but may involve the application of the ICRP concept of Reference Animals and Plants (RAPs). Whether or not reference biospheres are necessary is also subject to discussion, as is the topic of whether assumptions around present-day living habits and present-day agricultural practices are appropriate for all climate scenarios. For example, under a warmer climate, greater water intake may be required. One approach to addressing this could be to modify current data with respect to climate scenarios. Alternatively, data on agricultural practices at reference sites could be applied, where available. Discussion amongst partners is required to address the ongoing topics and to support the development of the administrative regulation for calculating doses that will serve as indicators of the quality of a HLW disposal site.

Discussion

For a farming community, around 10 persons are being considered, comprising 4 adults and 6 children. The requirements for the community would drive behaviours (e.g. how many wells are required to sustain the community). The exposure assessment will require doses to be evaluated for both adults and children, with the representative person being the individual receiving the highest dose from the group.

An ERICA assessment approach was suggested for evaluating exposure to non-human biota. This offers a tiered approach to assessment that would be useful in moving from generic to site-specific assessments.

There can be real challenges faced in assessments when geosphere and biosphere aspects are considered separately, as is required in Germany as a result of different organisations having separate responsibilities. The BIOPROTA GBI work may help in addressing some of the challenges. A close interface will be required between the different groups to avoid potential inconsistencies in assessment assumptions.

2.5 REGULATORY IMPLICATIONS AND POTENTIAL BIOTA IMPACT OF A BELGIAN LEGACY SITE

Geert Biermans (FANC) and Jordi Vives i Batlle (SCK·CEN) presented.

2.5.1 The site

The site of interest is located in the north of Belgium, near to the medieval city of Lier. A river (Grote Nete) flows close to the site. Whilst the river is not of a large volume, there are two tributaries upstream – Grote Laak and Molse Nete. The Grote Laak tributary is linked with a phosphate legacy site. In 2002, a survey of the environment identified several zones in and near to former and active river flooding zones that had Ra-226 contamination above background levels. The contamination, ranging from 0.2 – 5 Bq/g Ra-226, was linked to discharges from the phosphate industry to Grote Laak. During the 1980’s, embankments had been constructed along the river to prevent agricultural land from flooding, reducing contamination from flooding events. The land in the area was largely wetland or meadows, with agriculture being limited to cattle grazing. The radiological risk was, therefore, considered negligible and the area was largely forgotten about until 2016, when a floodplain restoration project was initiated. In Flanders there was a large project aimed at giving more space to rivers in terms of restoring natural flooding zones to help mitigate the risk of flooding in Antwerp, which is located near to the Scheldt Estuary, into which the Grote Nete flows. The objective was to remove the embankments and restore wetlands. Consideration had to be given to whether or not the Ra-226 contamination could pose a risk to workers and around 2 million m^3 of NORM contaminated soil could be generated by the remediation of contaminated areas.

More detailed surveys have been undertaken of the area since 2016 to better understand the situation. Gamma surveys were performed using helicopters to identify the main zones requiring more detailed analysis. Three zones were selected, with the first site sampling campaigns running between April and August 2016. With the site contaminated as a result of the phosphate industry, zinc and cadmium were also likely to be present, which would pose a potential toxic hazard. An integrated approach was therefore taken with heavy metal analysis being performed by the regional authority and gamma spectrometry undertaken by FANC. The monitoring area was heterogeneous, with marshes, reed beds and canals present.

Ra-226 was found in the monitored area, as expected, and activity concentrations were comparable to those previously measured upstream. Co-contamination of sediments with heavy metals associated with the phosphate was confirmed. However, Cs-137 and Am-241 were also measured, which had not been expected. The radioactive contamination was associated with river sediments, with the highest activity concentrations being associated with the upper 50 cm (Table 2). Contamination was fairly homogenous, but a few hotspots were identified.

The source of the Cs-137 and Am-241 was found to be the upper tributary (Molse Nete) to which discharges from the Mol nuclear site were made. The site had been used for a Euratom project relating to radioactive fuel reprocessing with peak discharges occurring in the 1970's. Further monitoring and analysis identified the presence of other radionuclides associated with fuel treatment, such as Co-60 and Sr-90, at the site and from samples taken from the Molse Nete, confirming this as the source of these radionuclides.

Table 2. Ra-226, Cs-137 and Am-241 activity concentrations (Bq/kg) in sediment samples.

		Zone A		Zone B		Zone C	
Nuclide	***Depth (cm)***	***Average***	***Max***	***Average***	***Max.***	***Average***	***Max.***
^{226}**Ra**	0-50	1120 ± 900	2060	2000 ± 1100	3120	1700 ± 800	2350
	50-100	700 ± 1200	2890	200 ± 260	504	600 ± 1100	2200
^{137}**Cs**	0-50	160 ± 130	277	100 ± 70	177	120 ± 66	197
	50-100	80 ± 130	309	30 ± 60	99	30 ± 60	114
^{241}**Am**	0-50	80 ± 70	160	76 ± 6	80	83 ± 23	100
	50-100	-	250	-	20	-	51

A very conservative dose assessment has been undertaken for communication purposes, based around a residential scenario and the limited monitoring data. The calculated annual dose from Ra-226 was 1.6 mSv, for Rn-222 it ranged from 6 to 20 mSv and for artificial radionuclides the annual dose was 22 µSv. A more detailed assessment is considered likely to result in doses around a tenth of those calculated. Radon was therefore the main risk factor for which more measurements were needed. A detailed site-characterisation programme is ongoing, which includes a radon measurement campaign for local residential properties. The characterisation programme is being undertaken by FANC and the regional authority.

A strong correlation is observed between Ra-226 activity concentrations and cadmium (R^2 = 0.927), which allows Ra-226 to be predicted based on measured cadmium concentrations: the measurement of cadmium being both quicker and cheaper than for Ra-226. Conversely, the identification of target areas for monitoring of heavy metals resulting from the phosphate industry can be identified from gamma surveys. By using such a strategy, a successful and targeted site-characterisation programme can be developed.

Various stakeholders have been consulted, including members of the public. Whilst all stakeholders have things to say, the views can be diverse. It is therefore important to provide appropriate information to address a range of concerns.

The regulatory framework also posed some challenges. There are NORM regulations in place in Belgium, but some of the activity concentrations measured were above exemption levels. Regional legislation for heavy metals also needed to be considered. Addressing legacy sites with mixed contamination can be both time consuming and costly and the regulatory regimes may not be fully aligned. For example, there is no current legislation in Belgium requiring assessment of the impact of ionising radiation on non-human biota, but the impact of non-radiological contaminants on biota is required under chemicals legislation.

If restoration works are undertaken, consideration will be required as to where contamination will end up as a result of the disturbance and natural processes such as tidal influences and flood events. If contaminated soils are removed, thought will be needed around appropriate disposal options. Any decisions should be based on risk.

2.5.2 Environmental impact

There are three main regions in terms of sources.

- Grote Laak: Ra-226 and heavy metals primarily from past phosphate industry activities.
- Molse Nete: a range of radionuclides, including Co-60, Cs-137 and Sr-90 from historical liquid effluent discharges from the Mol nuclear site.
- Grote Nete: receives inputs from both Grote Laak and Molse Nete and flows to the Scheldt Estuary in the area of Antwerp. There are few aquatic plants present in the estuary to act as a barrier to sediment transport and little sediment transport is therefore observed in relation to tidal processes.

The key processes at play are flooding and dredging to prevent flooding, resuspension with rain, chemically affected sorption kinetics, physico-chemical speciation, hydrological transport and bioavailability, including impact on the soil-biota system. No additional contamination has occurred since 1980.

A trial assessment of impact to non-human biota has been undertaken using the ERICA tool and sediment activity concentrations from the FANC and SCK·CEN monitoring programmes. The initial assessment was undertaken using tier 2 of the ERICA approach and the default transfer parameters that are site-generic and conservative. All default reference organisms were included. For the terrestrial ecosystem assessment, contaminated sediment deposited on riverbanks was assumed as a source term. For the freshwater assessment the sediment was assumed to be within the riverbed.

Total weighted dose rates ranged from around 3 µGy/h to over 300 µGy/h, in excess of the ERICA screening value of 10 µGy/h. The screening value is not a limit, but rather is applied to screen sites from further study or identify where further study may be merited. Radium-226 was the key contributor to calculated doses.

A further assessment was undertaken using additional sample data and Ra-226 was again the key contributor, driving doses above the screening value. Results were quite consistent across the different samples.

Risk quotients for the most exposed reference organisms were around 15 for the terrestrial ecosystem and 40 for the freshwater ecosystem. In the terrestrial assessment, lichens, shrubs and grasses were the most exposed organisms whereas for the freshwater ecosystems it was the smaller animals (insect larvae, zooplankton and molluscs) that were the most exposed.

With dose rates exceeding the ERICA screening value, the site failed to be screened out at tier 2. The FREDERICA database was used to identify whether there was evidence that effects could occur at the dose rates calculated for the most exposed reference organisms, noting the conservative nature of the assessment. At the highest dose rates received by terrestrial vegetation there is a possibility of effects being observed, but not for terrestrial animals. There is also the potential for moderate abnormalities in freshwater molluscs.

A further assessment with more site-specific information, including site-specific concentration ratios, is planned. Work is in progress to derive the concentration ratios and to characterise the biosphere, to identify indigenous species that will be assessed as representative species. Of the site-specific values calculated to-date, some are higher and some lower than the default ERICA values.

A new project is planned around Grote Nete as a natural laboratory for studying the mechanisms at play with regard to the impact of flood control measures on historical contamination. The project will mutually support model and field investigations and will aim to answer the following key scientific questions.

- What are the main vectors of radionuclide and heavy metal mobilisation?
- What are the key processes at play?
- What is the combined impact of chemicals and radionuclides?
- What is the major sink for eventual immobilisation?
- Can predictive models be developed and validated?
- How can techniques and approaches for radiological impact including man and the environment be developed?
- Can impacts of chemicals and radiochemicals be assessed together in combination with ecological interactions?

The project will be structured around four aspects.

1. Inventory and characterisation.
2. Interaction of radionuclides with the hydrosphere and geosphere.
3. Interaction of radionuclides and pollutants with fauna (including microfauna) and vegetation.
4. Development of a tiered approach for assessing ecosystem impact in a multi-contaminant context.

Internal SCK·CEN funding will be used initially for the project, supporting PhDs.

Discussion

With Ra-226 being the key contributor to dose, consideration of dose from Rn-222 as a daughter product may be warranted. An alternative tool to ERICA is available that would allow dose from Rn-222 to be calculated.

The protection objective in terms of non-human biota is to ensure the protection of populations rather than individuals. As such, consideration may be warranted as to the level of impact in relation to population requirements. Should the results of assessment suggest populations may be at risk of impact then decisions will need to be taken as to whether remedial actions are required, noting that remediation can impact on biota.

ERICA provides a tiered approach to biota dose assessment that aims to mirror the assessment approach for chemicals, but more work is required to fully align the assessment approaches. Consistency is required if an integrated approach is to be applied. For example, site description should be consistent, as should sampling sites/locations. The assessment frameworks can differ, but consistency should be maintained wherever possible.

2.6 OVERVIEW OF THE TRANS-LARA PROJECT

Veronika Ustohalova (Öko-Institut) presented.

The TRANS-LARA project (transport and transfer behaviour of long-lived radionuclides along the causal chain groundwater-soil-surface-plant under consideration of long-term climatic changes) is funded by the German Federal Ministry of Education and Research. The main objective is to develop a deeper understanding of radionuclide transport mechanisms from groundwater, through soils, to plants under long-term climatic changes. Consideration is being given to how radionuclides enter the upper soil profile through capillary rise and how they are transported between soil layers. The project focuses on some key radionuclides (Pu, Tc, I, Se, U, Cm and Am). A further task of the project is to maintain competence and promote young scientists in the field of safety research in relation to the final disposal of radioactive waste.

The project is comprised of four work packages.

- Work package 1: Determination of soil parameters as a function of climate. Several representative soils will be selected for laboratory investigation.
- Work package 2: Groundwater and radionuclides in soils. Meso-scale modelling and lysimeter experiments of radionuclide transport from groundwater to soils and into plants.
- Work package 3: Investigating redox behaviour and speciation of radionuclides in different representative soils.
- Work package 4: Detailed description of the uptake of radionuclides by crops via the root pathway and development of a compartmental model for the transport of radionuclides from soils to plants and the accumulation of radionuclides in plant systems.

The project has been running for around 18 months and will run for a total duration of 3 years. The first approach to biosphere modelling is developing and approaches for experiments are being developed. The interlink of the experimental and modelling aspects of the project is illustrated in Figure 4.

The project partners are divided into two groups – one on experimental research that aims to provide parameter values to the second group that is focussed on the modelling aspects of the project, including development of a model of radionuclide transport and transfer in both short and long timescales. A database of parameter values and approaches is also being developed.

To study long-term climatic developments and soil genesis, both current and predicted soils are being investigated. The selection of current soils took into account soils in regions above potential repository sites to investigate how these could develop in response to climate evolution. The selection was therefore informed, in part, by documents supporting the repository siting process. The two most common soil types in the regions were selected. Boundary conditions for temperature and water fluctuations have been set, taking into account information on groundwater fluctuations in the regions of the reference soils. In parallel, extrapolations for climate change (colder and warmer) were used to identify two additional soils to investigate that could represent the possible future development of the two selected current soils. Lysimeter experiments are currently underway.

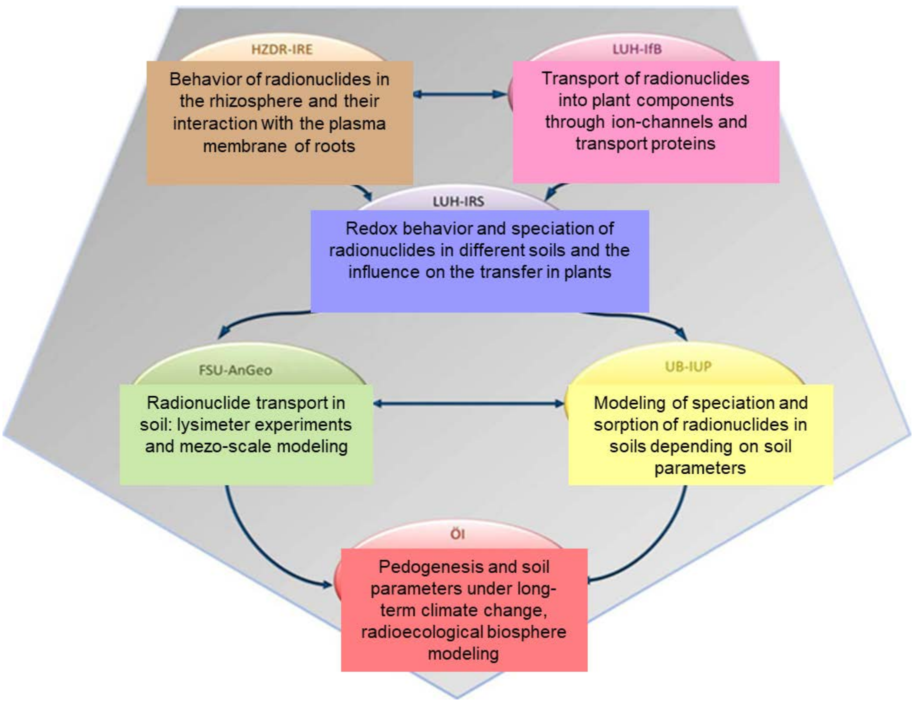

Figure 4. The TRANS-LARA experimental and modelling programme.

Lysimeter experiments have been designed to allow key hydrological and soil parameters (e.g. organic matter, pH, hydrological conductivity etc.) to be investigated in relation to upward (capillary rise) and downward (percolation) radionuclide transport.

Studies relating to the uptake of radionuclides by plants aim to identify which plant metabolite transporters are able to transport radionuclides into plants and determine root transfer factors for radionuclides in relation to the reference soils and selected experimental plants (carrots, potatoes, peas and wheat). The plants were selected due to the different parts consumed. Micro- and mesoscale lysimeter experiments are underway to investigate root uptake and the conditions under which selected radionuclides become incorporated within plants. Root uptake is being investigated under laboratory conditions with plants being dissected to analyse radionuclide accumulation in different tissues. Different experimental temperatures are being used, in line with current and future climate assumptions. The kinetics of transport are being investigated using injected oocytes.

There is a close interface between the experimental programme and the development of a soil-plant transport model that upscales the output from laboratory lysimeter experiments to larger scales (i.e. planted agricultural areas). An understanding of soil physics and of the main mechanisms influencing the larger scale is required to support this and several basic assumptions are necessary around hydraulics and radionuclide transport. Monte-Carlo analysis is being used to look at uncertainties around parameters. The model considers a layered soil profile and both water flow and radionuclide transport are represented and interconnected. Transport within plants will also be represented, based on experimental results.

Discussion

The work programme presented is complementary to work undertaken in the past at Imperial College where several lysimeter experiments were performed using mixed soils and either rye grass or wheat to look at radionuclide transport.

The soil-plant model performs well in relation to understanding of the processes at play. However, the longer-term lysimeter experiments have not yet concluded and model-data comparison has not, therefore, been possible to-date. The radionuclides being used in experiments were selected on the basis that they are relevant to the HLW repository programme in Germany but have not been well investigated and/or the transfer mechanisms are not well understood.

Consideration of climate change was used to bound the lysimeter experiments in terms of soil physics and soil temperature. Climate will, however, affect other aspects such as the vegetation period and irrigation requirements.

2.7 SE-SFL PROJECT RESULTS AND REFLECTIONS

Olle Hjerne (SKB) presented.

The SE-SFL project (safety evaluation of a repository for long-lived low- and intermediate-level waste (L/ILW) in Sweden) is nearing completion, with reports being finalised. The results presented were therefore preliminary.

The SE-SFL disposal concept is for L/ILW to be placed at a depth of around 500 m in crystalline bedrock. There will be two vaults (Figure 5). The BHA vault will be for legacy waste from historical nuclear research programmes and waste from research, hospitals and other industries. The inventory of the legacy wastes is very uncertain but comprises of less than 2% of the L/ILW activity to be disposed. The BHK vault will house 98% of the activity to be disposed, comprising metallic wastes from nuclear power plants.

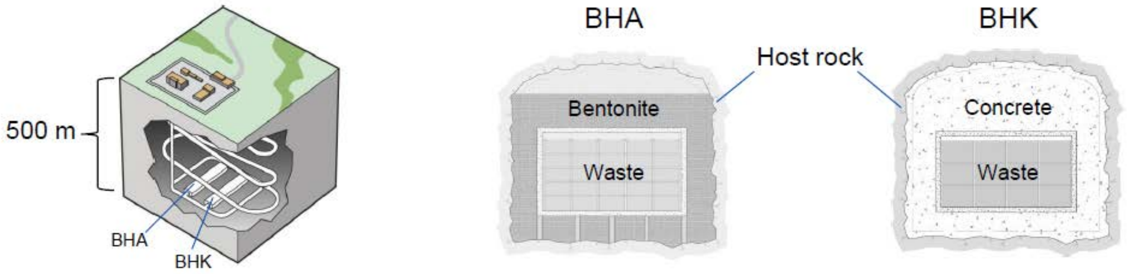

Figure 5. Disposal concept for the SFL repository for long-lived L/ILW.

Radiotoxicity associated with the BHK vault is initially higher than that in BHA but decreases over the first 1,000 years. With the BHA vault housing the more longer-lived radioactivity, radiotoxicity is maintained over time, becoming the more radiotoxic inventory after about 1000 years.

The safety principle for the SFL repository is retardation, to maximise sorption of radionuclides to allow for maximum radioactive decay, and to minimise release of radionuclides to the surface environment. The design of the facility has not yet been finalised and no site has been chosen. As such, the safety evaluation aims to answer the question as to whether the repository has the potential to function in a normal Swedish bedrock and to consider conditions necessary to ensure adequate performance. The safety evaluation will also help in guiding site selection and will help to focus future work.

Several evaluation cases have been analysed. The base variant case is a highly simplified case where it is assumed that there is no temporal development of climate or the biosphere although some temporal development of the repository itself is assumed. The case is not one that would be considered in a future safety assessment but was aimed at providing a basic understanding of what could happen within the repository. More realistic scenarios were also considered, including a glaciation variant and an increased-greenhouse-gas-effect variant.

No site has been selected for the SFL repository, but an internally consistent data set for Swedish conditions was available from the Laxemar site that was subject to characterisation during the site selection process for the Swedish spent nuclear fuel repository. The safety evaluation therefore made use of this data. A biosphere object consisting of a drained mire / agricultural field with a well in Laxemar was selected as the most likely discharge location for the base case. An integrated approach is being taken to modelling releases from the waste within the repository through to dose calculations in the biosphere.

Preliminary results for the base case indicate that Mo-93 and C-14 are important radionuclides for both BHA and BHK vaults. For the BHA vault, Cl-36, Tc-99 and the U-238 decay chain are also important. In many instances, time curves for geosphere releases for radionuclides are similar to the associated dose over time curves, but this is not always the case; the differences are driven by the different behaviours of the radionuclides and biosphere object properties. For example, Mo-93 is subject to retardation and decay within the regolith and accumulation in peat whereas C-14 accumulates in peat to a lesser extent and is more readily taken up by plants.

Several other calculation cases have been performed to consider implications of varying repository conditions (such as the effect of complexing agents or alternative back fill) and site-specific considerations (such as varying groundwater flow, alternative discharge areas or varying climate conditions). For alternative discharge areas, different Laxemar biosphere objects were considered, along with Forsmark biosphere objects, to investigate how different characteristics such as object size and thickness of layers (e.g. peat, till) affect model output.

In the base case, Mo-93 is the maximum contributing radionuclide to dose, but this is not always the case; for some calculation cases Cl-36 is key and for others Tc-99 is of greatest importance. The biosphere object properties influence the importance of different radionuclides. The ecosystem state is also important. For example, whilst key radionuclides differ in relation to different drained mire biosphere object properties, C-14 is always dominant in aquatic biosphere objects and Cl-36 is the most important radionuclide in permanent agriculture objects where the accumulation time is greater than for drained mires. Overall, small drained mires with thin layers are the objects for which the largest doses are calculated.

The dose results and variations with objects and their properties can be compared with other sources of uncertainty, such as the transfer of radioactivity for the entire simulation period from the near-field to the biosphere. For some radionuclides, retardation means that most of the radioactivity decreases within the repository through decay. Comparison with dose results helps to focus on what matters.

The safety evaluation is being used to consider the kinds of conditions required to meet the safety requirements for the SFL. For example, low groundwater flow and/or better sorbing concrete ensures the requirements for the BHK vault are met. Uncertainties in the legacy waste inventory to be disposed of in the BHA vault mean it is more difficult to conclude on the best solutions: an improved inventory is required.

The integrated analysis and evaluation of the near-field, geosphere and biosphere has been very useful, allowing a more harmonised approach to be taken to scenarios and analysing uncertainties. It also allows for more efficient resource allocation.

Discussion

The biosphere assessment is often considered to be ‘at fault’ where high doses are calculated, but it is important to recognise that uncertainties and pessimistic assumptions for the near-field and geosphere are as important as those for the biosphere. An integrated approach to modelling helps in the interpretation of results and also in refining the design etc. to improve the assessment outcome. However, as noted, knowledge of the waste inventory is crucial. If the inventory is uncertain then the focus may end up on the wrong radionuclides.

A position in Laxemar was selected for assessment purposes and combined with knowledge of the rock fracture network to determine the biosphere release area(s). Several potential release areas were identified, and the base case focussed on the most common area for releases. It was conservatively assumed that all radionuclides are released to that one biosphere object.

2.8 RWM WORK ON NON-RADIOLOGICAL POLLUTANTS

Ray Kowe (RWM) presented.

The Groundwater Daughter Directive (GWD) is aimed at protecting groundwater resources and human health. The key GWD requirements are to ‘prevent’ the input of hazardous pollutants into groundwater and to ‘limit’ the input of non-hazardous pollutants to ensure that such inputs do not cause pollution. In the UK, the provisions of the GWD are incorporated into the Environmental Permitting (England and Wales) Regulations 2016 (EPR16).

RWM is looking at addressing the requirement that the generic disposal facility (GDF) provides adequate protection against non-radiological pollutants. One aspect of this work has been the development of an assessment model to explore the behaviour of non-radiological pollutants.

RWM started a project in June 2016 to develop a total system model (TSM) to calculate the concentrations of non-radiological pollutants at defined points along the groundwater pathway in a range of geological environments. Example pollutants were selected for study by a screening process which resulted in 15 pollutants being selected for further study.

Two illustrative geologies taken from the 2016 RWM generic Disposal System Safety Case were selected for the study: higher strength rock (HSR) and lower strength sedimentary rock (LSSR). The 2013 UK inventory for geological disposal was used to derive the mass inputs for non-radiological pollutants. Concentrations were output at various points along the groundwater pathway, especially at interfaces.

Results for the HSR show the following.

- All organics degrade before the container fails.
- Mean peak concentrations in surface water receptors meet the comparison standards for all modelled pollutants, except lead and beryllium in the well.
- Mean peak concentrations of all modelled inorganic pollutants exceed comparison standards at all locations in the HSR.

Results for the LSSR show that:

- All organics degrade before the container fails.
- Mean peak concentrations in surface water receptors meet the comparison standards for all modelled pollutants.

RWM has recently started a follow-up modelling project which will:

- carry out runs for other non-radiological pollutants in addition to the 15 already modelled;
- use the latest (2016) inventory;
- have a more physical representation of release rates (the previous model had instantaneous release from metals); and
- include the spread of the contaminant plume in the groundwater flow model (previously 1D).

This work will be completed in February 2020.

Discussion

Compliance with the GWD will be assessed through comparison of pollutant concentrations with constraints at different compliance points rather than by evaluating impacts on people and/or the environment. Neither compliance points not constraints have as yet been set for pollutant concentrations in groundwater. It is not just pollutants (radioactive and non-radioactive) associated with wastes that need to be considered. Issues around the use of concrete in the disposal system also need to be investigated, such as the potential for plumes of high pH groundwater from the disposal system.

There are inconsistencies in the way that non-radioactive contaminants are considered as compared with radioactivity. Assessments of conventional (non-radioactive) disposals typically focus on the short-term, whereas longer timescales are considered for radioactive waste disposals.

2.9 STUDY OF TRANSPORT PROCESSES IN THE GEOSPHERE-BIOSPHERE INTERFACE – A RESEARCH PROJECT INITIATED BY SSM

Shulan Xu presented on behalf of KTH Royal Institute of Technology.

There has been a long history of developments in biosphere modelling for radiological assessments from the BIOMOVS II project that began in 1991 through to current programmes such as the IAEA MODARIA II programme. These programmes have been aimed at developing greater international consensus on biosphere assessment. The geosphere-biosphere interface (GBI) remains a subject of interest. The IAEA BIOMASS project introduced example reference biospheres that had different GBI's that can be addressed using site-generic models. Site-specific models tend to be more complex, such as that developed by SKB for the Forsmark site that considers post-glacial land uplift and landscape development. Results from this complex landscape development model then inform the biosphere model.

To support the regulatory review of SKB's safety assessment for a repository at Forsmark, SSM developed their own independent biosphere models, including models to study and enhance understanding of transport processes in the GBI. There is also an ongoing study to model the effects of stream sub-surface (hyporheic) flow on the discharge of deep groundwater. Site observations (radon and temperature data) are being made within a catchment area to compare against modelling results.

There is a lot of information available from the catchment relating to the presence of different soils and the stream network as well as topography data and bedrock hydraulic conductivity. Hydraulic modelling is being performed using COMSOL[b]. The model considers topographically controlled flow and heterogeneous hydraulic conductivity that reflects the soil-type distribution and reduction of hydraulic conductivity in bedrock across the whole catchment. The model allows discharges across the whole area to be identified. The upwelling of groundwater occurs in localised areas that correspond with topographical lows.

Surface water flow modelling is dependent on the topography, the elevation of the water surface and the heterogeneity of the stream bed. There are different scales of water circulation in streams and rivers, ranging from regional groundwater circulation to hyporheic flow that occurs below streams. The hyporheic flows can vary in size and groundwater discharge may occur in small areas within streams. Superimposing results from deep groundwater upwelling modelling with that of surface flow modelling allows 'hot spots' for discharges to be identified, as illustrated in Figure 6.

[b] See (https://uk.comsol.com)

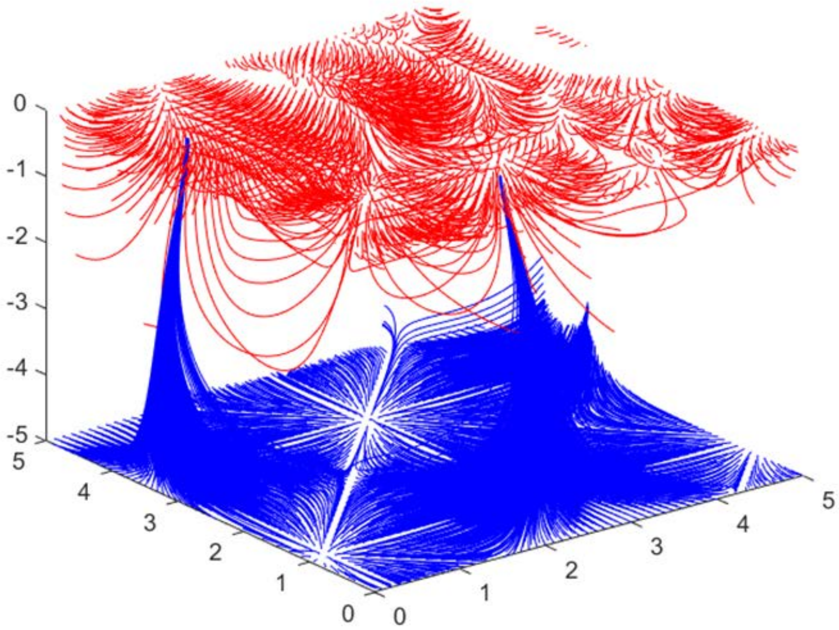

Figure 6. Pinhole discharge of upwelling groundwater (blue) in relation to hyporheic flow (red).

These discharge locations can be identified in the field through temperature anomalies in surface waters. Measurements taken in the field have identified such locations with groundwater discharge leading to sudden drops in water temperature. Radon measurements have also been made in the same stream under reduced flow and flooding conditions to investigate the effects on measurements. Higher radon concentrations have been recorded under low stream-flow conditions.

Hyporheic flows can therefore influence the discharge of groundwater to the surface, resulting in small areas that may represent 'hot spots' for the discharge of radioactivity to the surface environment. In addition to monitoring and modelling the discharge of groundwater to streams, the intention within the project is to consider other biosphere objects where discharge hot spots could occur, such as mires. A recent publication (Lidman et al., 2013[c]) considers the distribution of uranium and daughters, measured in a small mire in northern Sweden, where such hot spots have been observed, illustrating that this is a phenomenon that occurs not just in streams, but also in wetlands.

The project is ongoing and aims to study the detailed processes at the discharge locations for groundwater in different biosphere objects and to consider findings in terms of implications for dose assessment models, e.g. to consider whether assumptions of mixing throughout model compartments are appropriate.

[c] Lidman et al. (2012). Distribution and transport of radionuclides in a boreal mire – assessing past, present and future accumulation of uranium, thorium and radium. Journal of Environmental Radioactivity: 121: 87-97.

Discussion

One of the objectives of the project is to look at how to derive appropriate statistics for water fluxes for use in compartmental models. If there are hot spots for groundwater discharge to the surface system then, depending on the biosphere receptor, there could be potential for flushing out to downstream biosphere objects. This could affect radionuclide behaviour and whether sediment accumulation or water transport of radionuclides is of primary interest.

2.10 SKB AND THE COMING R&D PROGRAM

Ulrik Kautsky (SKB) presented.

The current biosphere research and development (R&D) programme at SKB covers three repositories (one for short-lived radioactive waste, one for intermediate level waste and one for spent nuclear fuel) for which SKB is responsible. SKB is also responsible for a central interim storage facility for spent nuclear fuel.

A main focus of the current R&D programme, as required by SSM, is on the SFL safety evaluation (see Section 2.7) and siting of the facility. In addition, a license application for the extension of the operational LLW repository (SFR) is due to go before the Environmental Court in September 2019. A preliminary safety assessment report for SFR is due in 2021. A further focus of the programme is on improving confidence and the logistics for waste management. The programme extends 6 years into the future and is revised every three years. The 2019 report is due to be submitted to the government in September with an English version being available toward the end of the year. Following submission, the programme will be reviewed by SSM and by external reviewers with approval from the government anticipated in early 2020. The programme provides the foundation for securing funding from waste producers.

Part 2 of the 2019 R&D report is focussed on waste and disposal. The SFL safety evaluation forms a new chapter as compared with the previous 2016 R&D report. Other topics include L/ILW, spent nuclear fuel, canisters, cement-based materials, clay and closure, rock, surface ecosystems and climate.

The R&D programme is not independent of safety assessments; rather, they are closely linked, with review also being an important aspect. Safety assessments are undertaken for each facility every ten years, with review of the assessment programmes then feeding back into R&D needs. Other important aspects include the retention of knowledge and being up-to-date in terms of scientific developments, for which the BIOPROTA and IAEA MODARIA programmes are beneficial.

The surface ecosystems R&D programme includes uptake pathways and mechanisms for radionuclides in various organisms, temporal and spatial heterogeneity of the landscape, radionuclide transport and accumulation processes and radiological, biological and chemical properties of potentially important elements. In terms of what is important for assessments, four radionuclides consistently arise as key contributors to dose: C-14, Mo-93, Cl-36 and Ni-59, with Kd and concentration ratios being key parameters. The range of values for these parameters can span two orders of magnitude within different ecosystems (mires, lakes etc.) although the range for agricultural systems tends to be lower due to their being relatively constrained systems.

Concentration ratios are important parameters with large variations being evident, which affect assessment outputs. An alternative to the use of concentration ratios is to take a more mechanistic approach to modelling the uptake of radionuclides into and through the food chain. For example, transpiration of plants can be measured, as can net primary production. Variation in such parameters is considerably less than that seen with concentration ratios. A mechanistic ecosystem approach may potentially help to reduce uncertainties.

Chlorine has been identified as an important element. As such, chlorine turnover in ecosystems is being investigated with a conceptual model being developed. Carbon and methane turnover is a further topic of interest, particularly methane fluxes in lakes.

In terms of uptake pathways for radionuclides in various organisms, running waters are a particular area of interest. SKB also participates in the ongoing BIOPROTA C-14 work programme.

Spatial and temporal variation and climate are important subjects due to ongoing shoreline displacement at sites being considered in Sweden. Current work is looking to see whether the UNTAMO model from Posiva can reproduce what is observed at the present-day. For climate, considerable knowledge and data have been gained through research programmes in Greenland and at Krycklan in northern Sweden where research at a large catchment has been undertaken with regard to climate, carbon cycles and on the interactions of the uranium decay chain with organic matter. The R&D programme relating to spatial variation has also considered surface hydrology and vertical fluxes of groundwater, and the application of a coupled reactive transport approach for radionuclides from groundwater into the surface environment to consider where elements may accumulate. The profile of vertical distributions of elements varies according to their different behaviours; this is particularly important for the uranium decay series for which differences in behaviour affect the transport of elements to the surface system.

There is interest in publishing a Nordic database of data arising from the site characterisation programmes and relating to the radiological, biological and chemical properties of potentially important elements.

Other R&D topics of interest include approaches to surveying pool frogs, how nitrogen from blasting and groundwater affects surface waters, and taking account of the latest projected sea-level data for the next 10,000 years in terms of implications for the construction of facilities at Forsmark, including taking account of the large uncertainties. The R&D programme also includes continued participation in the IAEA MODARIA II programme and BIOPROTA.

Discussion

A report on assumptions and uncertainties around sea-level rise is due to be published by SKB. It includes consideration of arctic ice melt.

2.11 STAKEHOLDER ENGAGEMENT: SITEX NETWORK

Maryna Surkova (FANC) presented.

European Council Directive 2011/70/EURATOM established a community framework for the responsible and safe management of spent nuclear fuel and radioactive wastes, noting broad acceptance for deep geological disposal for high level waste (HLW) and spent fuel. Safety cases are required to support decisions on the disposal of spent nuclear fuel and HLW. Regulators require skills and experience to support the regulatory review of those safety cases.

In 2012, the EURATOM SITEX programme was launched that aimed to characterise, at a national level, the expertise function (Figure 7) devoted to the scientific review of safety cases for geological disposal of radioactive wastes and spent nuclear fuel. A SITEX 2 project then ran from 2015 to 2017, with the objective of implementing practically what was developed during the first project in terms of an expertise function network. The main purpose was to increase the quality of the expertise function through improved interactions with civil society throughout the waste management decision-making process. This required conditions and means for engaging with civil society to be identified.

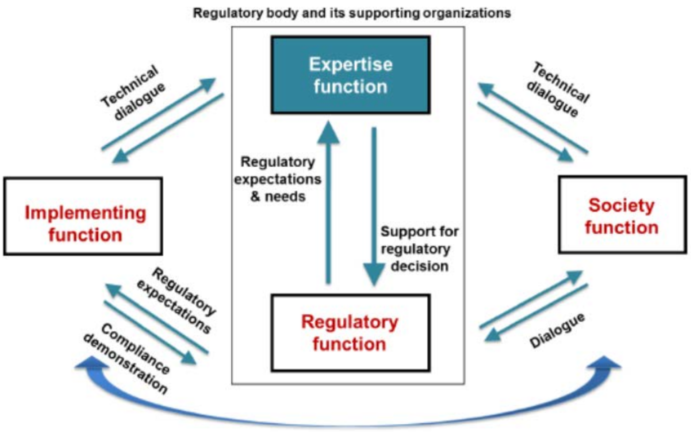

Figure 7. Functions associated with the scientific review of safety cases.

Different stakeholders will have varied views on the definition and implementation of a safety culture. One of the outcomes of the project was the development of a shared safety culture concept, including conditions for the constructive engagement of civil society throughout the review process of a safety case to support the building of trust.

A strategic research agenda was developed together with civil society on aspects relating to the biosphere. The public were interested in the effects of climate change on geological stability and what this means for siting (see [d]). Other important issues identified included data acquisition, uncertainties associated with radionuclide transport in the environment and biosphere properties and what this would mean for site selection. The need for independent modelling was also identified.

A path evaluation process was developed around the engagement of the public in safety cases that is intended as a 'serious' game with the objective of identifying, structuring and discussing issues that would really matter to different groups of stakeholders from the current radioactive waste situation through to a safe conclusion (i.e. geological disposal). The game is structured around a board that outlines timeframes and different wastes. Special cards have been developed on different conditions, such as what would happen to wastes if there was an operational failure. The cards are intended to promote discussion around what the conditions would mean for the safety case.

[d] http://www.mkg.se/en/in-a-new-statement-the-swedish-society-for-nature-conservation-andmkg-demand-completions-in-the-lic

Following the completion of the SITEX 2 project a SITEX Network was formed (www.sitex.network/) to enhance and foster cooperation at the international level in order to achieve a high quality expertise function in the field of radioactive waste management safety. The network is aimed at supporting nuclear regulatory authorities and civil society. Additional members to the network are welcome.

2.12 CURRENT STATUS OF THE SWISS PROGRAMME AND RECENT BIOSPHERE ACTIVITIES

Jűrgen Hansmann (ENSI) presented.

A general feasibility study for the geological disposal of HLW and L/ILW radioactive waste in Switzerland has been completed by Nagra, along with a sectoral plan that was submitted in 2008. Currently, radioactive waste disposal in Switzerland is in a site-selection process, which is comprised of three stages. Stage 1 involved a study of generic safety considerations to identify where disposal sites could be located, Stage 2, which recently completed, used provisional safety analyses to narrow down the number of sites, and Stage 3, now ongoing, involves identifying preferred site(s) and undertaking a safety analysis for a generic license application. The site-selection process is undertaken for both waste types, but disposal at a combined site is possible. It is intended that the site-selection process will end with a general licence in 2030 that will be followed by an operating licence for the disposal of L/ILW being granted around 2050 and in around 2060 for HLW disposal.

During Stage 1, criteria were defined to support site selection, allowing sites to be compared in terms of advantages and disadvantages and helping to narrow down the number of potential sites. Some dose calculations were then performed for the remaining sites during Stage 2 of the process. The calculations were undertaken by Nagra, with ENSI performing independent calculations as part of the regulatory review process. For C-14 some differences were notable between the calculations. By the end of Stage 2, the number of possible sites had been reduced from six to three (Jura Ost, Zűrich Nordost and Nördlich Lägern). Stage 3 will further narrow down the sites to one for each waste type (or one combined disposal site).

Recent biosphere related work at ENSI has included a report documenting the international status regarding the protection of non-human biota in the context of geological disposal of radioactive waste. The report was commissioned as input to the revision of ENSI's regulatory guideline G03: specific design principles for deep geological repositories and requirements for the safety case.

In terms of future work, the Stage 3 siting process is a key focus. A biosphere model will be used to provide independent regulatory review of Nagra's assessments, including assessments of stylised biospheres for different climates.

Discussion

The difference in C-14 dose assessments undertaken by Nagra and ENSI likely stems from differences in the parameter values applied within assessment models, such as diffusion coefficients. With the sites being assessed being in relatively close proximity, it was not necessary to develop location-specific models.

Nagra will be responsible for deciding whether or not to co-locate the L/ILW and HLW facilities.

2.13 ONGOING BIOSPHERE WORK INITIATED BY SSM

Maria Nordén (SSM) presented.

Projects initiated by SSM that may be of interest to BIOPROTA participants were briefly introduced. These consist of the following.

- An analysis of C-14 in marine biota samples that began in the summer of 2018. The project aims to increase knowledge on C-14 from nuclear power plants in marine ecosystems and contribute to the development of the national and international ability to analyse C-14 in biota samples using fast, cost-effective and accurate analytical techniques. The project also aims to produce a C-14 dataset for a Swedish marine ecosystem that could be used for the validation of models, which could be of interest for future BIOPROTA model-data intercomparison exercises. Initial work is presented in SSM report SSM2018-1476. Preliminary results indicate that C-14 activity concentrations are greater in blue mussels as compared with bladder wrack, with the lowest observed concentrations being in fish (wrasse).
- A PhD project on transport processes in the geosphere-biosphere interface, the final thesis of which is planned for 2020 (a recent publication associated with the project is available[e]). This is related to the project studying water fluxes in the geosphere-biosphere interface zone used in biosphere modelling for long-term safety assessments, which began in spring 2019 (see Section 2.9).
- A project looking at long-term variations of radioactive substances and metals in two species of brown seaweed (*Fucus vesiculosus* and *F. serratus*) sampled along the west coast of Sweden. Time-series data are available for a period of over 50 years. A draft report (SSM2018-905) is available.
- A study of Cs-134 and Cs-137 in marine benthic food webs to further understanding of effects and trophic transfers. The final report on methods is available (SSM2015-1294). Results will be written up for publication as an Open Access paper.
- A study on the effects of long-term exposure to ionising radiation on Chernobyl's treefrogs, for which a final report is available (SSM2017-269). Results are also due to be written up for publication in a peer-reviewed journal. A further project on the physiological effects of chronic exposure to low-dose radiation in Chernobyl amphibians began in summer 2018 and is ongoing.
- A new project began in spring 2019 looking at the long-term redistribution of Cs-137 in forest ecosystems.

[e] Mojarrad, B. B., Riml, J., Wörman, A., & Laudon, H. (2019). Fragmentation of the hyporheic zone due to regional groundwater circulation. Water Resources Research, 55. https://doi.org/10.1029/2018WR024609.

3. TOPICAL SESSION ON RADIONUCLIDES OF SPECIAL INTEREST

The topical session on radionuclides of special interest was aimed at providing an opportunity for presentation and discussion around recent research and model/assessment experience in addressing key radionuclides in safety assessments. The session began with a round table discussion on radionuclides of special interest for waste disposal programmes and was followed by presentations on key radionuclides in the work programmes of participants and summaries of work programmes undertaken within BIOPROTA on special radionuclides.

3.1 SPECIAL INTEREST RADIONUCLIDES

The outcome of the round table discussion on radionuclides of special interest is detailed in Table 3. It is important to recognise that interests can change over time and, as such, the list of key radionuclides should be regularly revisited.

Table 3. Radionuclides of interest for radioactive waste disposal programmes, where interest depicts the relative number of meeting participants noting interest in each radionuclide.

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	

3.2 CHLORINE-36 R&D: A BRIEF SYNOPSIS ON BACKGROUND AND HISTORY

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

Chlorine is one of the most abundant elements and is ubiquitous in various environments and is an essential nutrient for humans and plants. In addition to stable chlorine, there are several radioactive isotopes, including long-lived Cl-36 that occurs naturally, but can be enhanced through anthropogenic production.

There have been several publications since the early 1990's on stable chlorine and Cl-36 and, in 2001, a contract with Steve Sheppard was set up by Andra relating to the transfer of Cl-36 in the biosphere, which provided the basis for the development of Andra's specific activity model for Cl-36. Further research relating to Cl-36 in the biosphere continued after this time, encouraged by the opinion of IRSN in their 2005 Dossier (Rapport DSU number 106). There has also been work undertaken within BIOPROTA on Cl-36, including an international forum that was held in 2006 and was followed by two model inter-comparison exercises in 2008 and 2009 (see Bytwerk et al. 2011)[f]. This, and other work on Cl-36, has supported further model development work, including research undertaken by Andra and EdF on the sources, partitioning and transformation rates and impact of accumulation and persistence of stable chlorine and Cl-36, as illustrated by the following publications:

- Redon, P-O., Abdelouas, A., Bastviken, D., Cecchini, S. Nicolas, M. and Thiry, Y. (2011). Chloride and organic chlorine in forest soils: storage, residence times, and influence of ecological conditions. Environmental Science & Technology, 45: 7202-7208;
- Van den Hoof, C. and Thiry, Y. (2012). Modelling of the natural chlorine cycling in a coniferous stand: implications for chlorine-36 behaviour in a contaminated forest environment. Journal of Environmental Radioactivity., 107: 56-67;
- Gustavsson, M., Karlsson, S., Öberg, G., Sandén, P.,Svensson, T.,Valinia, S.,Thiry, Y. and Bastviken, D. (2012). Organic matter chlorination rates in different boreal soils: the role of soil organic matter content. Environmental Science & Technology, 46 (3): 1504-1510;
- Redon, P-O., Jolivet, C., Saby, N., Abdelouas, A. and Thiry, Y. (2013). Occurrence of natural organic chlorine in soils for different land uses. Biogeochemistry, 114: 413–419;
- Pupier, L., Benedetti, L., Bouchez, C., Bourlès, D., Leclerc, E., Thiry, Y., Guillou, V., ASTER Team (2016). Monthly record of the Cl and ^{36}Cl fallout rates in a deciduous forest ecosystem in NE France in 2012 and 2013. Quaternary Geochronology, 35: 26-35;
- Montelius, M., Svensson, T., Lourino-Cabana, L., Thiry, Y., Bastviken, D. (2016). Chlorination and dechlorination rates in a forest soil – a combined modelling and experimental approach. Science of the Total Environment, 554-555: 203-210;
- Montelius, M., Thiry, Y., Marang, L., Ranger, J., Cornelis, J-T., Svensson, T. and Bastviken, D. (2015). Experimental evidence of large changes in terrestrial chlorine cycling following altered tree species composition. Environmental Science & Technology, 49: 4921-4928; and,
- Radiotracer evidence that the rhizosphere is a hot-spot for chlorination of soil organic matter. Montelius M., Svensson T., Lourino-Cabana B., Thiry Y. & Bastviken B. (Plant & Soil, submitted).

There are variable amounts of Cl-36 in the environment and research activities have aimed to identify the reasons for this. This has included Andra working in cooperation with EdF to investigate reasons for the large spatial and temporal variation observed for Cl-36. The agreement between Andra and

[f] Bytwerk et al. (2011). Sources and significance of variation in the dose estimates of ^{36}Cl biosphere transfer models: a model intercomparison study. Journal of Radiological Protection, 31(1), 63.

EdF also extends to the development and evaluation of a simple dynamic model to improve the representation of the Cl-36 biogeochemical cycling in a terrestrial forest.

The collaborative programme between EdF and Andra has been partly driven by the fact that French nuclear power plants are due to be decommissioned in the near future, with Cl-36 being one of the radionuclides of interest arising from decommissioning activities. One of the questions that is being asked is whether or not Cl-36 releases to the environment associated with decommissioning operations will be distinguishable from natural background. One objective of the joint Andra-EdF project is therefore to determine the background levels of Cl-36 in the French environment, taking account of temporal and spatial variability. A second objective is to develop a mathematical model to estimate Cl-36 transfers in terrestrial environments to enhance understanding of Cl-36 dynamics, notably in forest and grassland systems.

For grasslands, a simplified model has been developed within an EdF internal project. The model has been tested against experimental data generated through a Swedish PhD study. Both passive and active root uptake are considered. Atmospheric deposition and plant interception are processes that still need to be added to the model.

Until recently, chloride, which is the dominant form of chlorine in the terrestrial environment, was considered to be inert and highly mobile, following water. The current view, however, is that chlorine is highly reactive in soil, where it can undergo transformative processes with chlorination and dechlorination being important processes for the cycling of chlorine in soils.

For stable chlorine, there is a tendency for greater atmospheric deposition close to the sea, but the concentration in soil is not correlated with the deposition flux. The best regressions are obtained for both organic chlorine and total chlorine with organic carbon and pH. For Cl-36, variations in the deposition flux are observed with latitude.

An initial model was developed and published by Van den Hoof & Thiry (2012). The model comprised of seven compartments with additional source and sink terms. Each compartment is linked with transfer rate coefficients. The model was initially parameterised using site data for a Mol pine stand, supplemented with literature data. The results were good, but quite site-specific. The model has therefore been updated more recently with a larger, more site-generic dataset. The model is being applied to try and identify the key transfer processes affecting dynamics of stable chlorine and Cl-36 in the soil-tree system and to illustrate the partitioning of stable chlorine and Cl-36 and their residence times in the system. The updated model that is being developed will allow sensitivity analyses to be performed.

The ranges of parameter values have been determined from measurements at different sites, including Breuil, Mol and the RANECOFOR network that consists of 51 plots. Literature data have also been used. Leaching parameters linked to inorganic pools were determined from water balance data from Mol and Breuil. The model has been applied to atmospheric deposition scenarios based on observations at the RENECOFOR network and observations at the French observatory site (OPE). A constant deposition rate was assumed for stable chlorine whereas for Cl-36 it was necessary to reconstruct time dependent and constant fluxes following nuclear weapons tests from different sources of information and reconstructing those fluxes to account for latitude. There has been a reasonable agreement between model simulations and observations from the field. Of the Cl-36 found in the soil, around 90% may have been associated with fallout from weapons tests. The results are currently being prepared for publication in the scientific literature.

In terms of lessons learned, both foliar and root uptake have been identified as being important processes and a strong interaction between vegetation and soils is observed. Sensitivity analysis has shown that root uptake can influence both the inorganic and organic chlorine pools in the soil. The natural production of organic chlorine in soil is the main source of chlorine persistence in the system and the chlorination rate is therefore important, which can be affected by environmental conditions. An extra model calculation has indicated that a maximum of around 2% of the total atmospheric deposition of chlorine entering the system could be lost through volatilisation. Volatilisation remains an interesting research topic, along with chlorination.

Discussion

The overall aim in terms of model development was to enhance understanding of chlorine dynamics in the system. The model was therefore intended as a questioning tool to investigate the complexities of chlorine behaviour. A simple dynamic modelling concept was found to be suitable for illustrating soil-plant interactions, taking account of both organic and inorganic chlorine cycles. If the interest is solely on plant contamination by Cl-36 then a specific activity model would be sufficient. However, if long-term contamination of soil etc. is of interest, then a more dynamic modelling approach is required. The model developed is now ready for further site-specific application and/or validation.

3.3 SOME IMPORTANT ELEMENTS FOR SKB

Ulrik Kautsky (SKB) presented.

Information on many elements of relevance to radioactive waste management is scarce and some important elements do not behave as assumed in standard models, requiring special treatment such that common approaches to modelling behaviour, such as the use of concentration ratios, may not be appropriate. It is also important to recognise that the environment changes substantially over the timeframes of interest for radioactive waste management and behaviour of elements in the future may therefore differ from that in the present-day environment. To address some of the issues it is common practice to identify a short-list of key radionuclides, but in doing so, radionuclides that may be key at future times may be missed. If the list of key radionuclides changes through the different stages of assessment programmes, this can cause issues for biosphere assessment.

A considerable amount of data on elements has been obtained by SKB from site studies, including coordinated measurements for many elements across different environmental media. However, the current site has lakes present that are extremely unusual for the country, having high pH and being calcium rich due to the erosion of sedimentary rocks that were transported from the Baltic by glacial processes, which will affect element behaviour. It is therefore important to understand the mechanisms of the system rather than focussing on key elements in isolation since the system will control element behaviour.

SKB has commissioned a review of the sources, transport and losses of methane in the biosphere[g]. Some findings from the review are that there is a wide range in methane fluxes from wet environments and that few site-specific estimates are available for natural methane production and oxidation in sediments. Field studies have therefore been initiated. There is a lot of organic carbon

[g] Ikonen, A.T.K. (2019). Preliminary title: Sources, transport and losses of methane in the biosphere: a review. To be published.

associated with the SFR disposal facility and assessments must therefore consider what will happen to this carbon following release. If it is metabolised and enters the foodchain, then it could be an issue. If it is released to lake environments, then whether it will be oxidised needs to be considered.

In July 2018, methane fluxes and concentrations were measured in Forsmark lakes and compared with lakes outside Forsmark. The fluxes of methane from Forsmark lakes were found to be considerably higher. This remains an ongoing topic of study.

Studies have also been made of methane and carbon dioxide emissions from running water. The highest emissions were associated with small hotspots, consistent with the findings of research initiated by SSM (see section 2.9). Large temporal and spatial variability in the partial pressure of carbon dioxide (pCO_2) has been observed in lakes and correlations have been investigated to try and identify the drivers behind these variations. For spatial variations, distance to shore, stream inlets, spatially varying piston velocity and photosynthesis are drivers whereas for temporal variations the key drivers are rain and wind events, lake mixing events, spring ice melt and diurnal variability.

Chorine is another element of importance for SKB. In terrestrial systems and most chlorine is in the organic form in soils. Volatilisation of organic chlorine can be an important loss mechanism (data are available from SKB report TR-18-09[h]). Whilst this can be an important loss mechanism, the remaining chlorine in soils can still be important for dose assessments. A sampling campaign is underway at Forsmark to look at the speciation of chlorine in different environments and layers throughout forests. High concentrations of chlorine have been measured in the field layer. Initially it was thought that this arose from sampling issues, but repeat sampling gave the same results. The reasons for these higher concentrations are not known at this time. The fact that such an unusual finding was made for what is a well-studied element raises concerns for other less well-studied elements.

In addition to report TR-18-09, the following publications provide information from the SKB programme relating to chlorine:

- Svensson, T., et al. (2019). *Preliminary title*: Chlorine distribution in vegetation and soil in boreal ecosystems along dry to wet gradients of different age. To be published.
- Svensson, T., Löfgren, A., Kautsky, U., Saetre, P., Avila, A.R., Bastviken, D. (2016). Chlorine distribution in a forest ecosystem gradient - role of understory. European Geosciences Union (EGU) General Assembly 2016, April 2018, Vienna, Austria.

A further element of interest for SKB is nickel. In general, nickel correlates well with other elements with the exception of one lake, where a very different trend has been observed. The reasons behind this difference are being investigated. A sediment core has been studied from the lake that was isolated from the Baltic Sea around 2,600 years ago. Variations in the nickel and cobalt mass ratios at the time of isolation are evident. The abundance of nickel and cobalt in water has not, however, changed considerably in changing from marine to freshwater conditions.

[h] Svensson T. (2019). Measurements and fluxes of volatile chlorinated organic compounds (VOCL) from natural terrestrial sources. Measurement techniques and spatio-temporal variability of flux estimates. SKB Technical Report TR-18-09.

For both molybdenum and uranium, redox conditions and the presence of organic matter are important influences on behaviour. Oxidation states can vary considerably with depth, affecting element behaviour. Biological processes also influence behaviour.

For many elements (e.g. iron, manganese and molybdenum), a bimodal distribution is observed for site-specific Kd values, largely as a result of their being redox-sensitive elements. The chemical environment also changes with landscape evolution. For example, calcium concentrations and pH are currently high around the Forsmark area but are likely to reduce to levels more representative of inland areas as shoreline displacement progresses. Seasonal variation is also observed with regard to pH and calcite concentrations that can also influence element behaviour, such as speciation. Data selection for assessments therefore needs to be informed by knowledge of the environment. The following SKB reports on the behaviour of elements are recently published or will be available in the near future:

- Lidman, F., Källström, K., Kautsky, U. (2017). Mo-93 from the grave to the cradle. Report from a workshop on molybdenum in radioactive waste and in the environment. SKB P-16-22, Svensk Kärnbränslehantering AB.
- F. Lidman, M. Jaremalm, L-O. Höglund, M. Tröjbom and S. Grolander (2019). Mobility and sorption of elements in a developing landscape- Pre-study of the effects of changing chemical conditions on mobility of elements. To be published.
- Lidman, F. (2019). Review of site data regarding Ni, Mo. To be published.

It is not just behaviour in the biosphere that is of concern for assessments; assumptions made for the near-field and the geosphere can have large implications for biosphere assessments. For example, a zero Kd is applied to molybdenum in the geosphere by SKB in assessments. If a non-zero Kd is applied then it does not reach the biosphere.

The natural behaviour of elements in the environment can also be useful in forming complementary arguments for safety assessments. For example, the natural flux of Ra-226 has been studied in relation to groundwater and is two orders of magnitude greater than that associated with radioactive waste disposal.

Discussion

The field layer in which high chlorine concentrations were measured consists of annual and perennial vegetation plus some shrubs. High concentrations of other elements have also been observed and a correlation with potassium and sodium concentrations has been noted. The complete data set needs to be fully evaluated to further understanding. Vegetation can become stressed in low chlorine environments and adaptation may have occurred, leading to preferential uptake.

3.4 SUMMARY OF BIOPROTA WORK PROGRAMMES ON SPECIAL RADIONUCLIDES

Several work programmes have been undertaken through BIOPROTA on radionuclides of special interest for assessments, including C-14, Cl-36, Se-79, Ra-226 and the U-238 decay series. Brief presentations were given to summarise the work undertaken. All publications are available from www.bioprota.org.

3.4.1 C-14 current status and continuing issues for discussion

Graham Smith (GMS Abingdon) presented.

C-14 is a key radionuclide for many. For example, C-14 in drinking water dominated doses in Posiva's BSA-2012 assessment. Carbon-14 is also particularly important in relation to graphite core reactors for which a lot of work has been done in the UK to ascertain whether graphite disposal should be deep geological or near surface, which would have significant cost implications.

Carbon is fundamental to life and is naturally present both as stable carbon and C-14. Assessments can therefore be complex. For routine releases there is a tendency to use specific-activity models, which could be applied to waste disposal situations. However, careful consideration needs to be given in applying specific-activity models as to whether stable and radio-carbon pools are in equilibrium. Some mechanistic thinking is therefore appropriate.

Studies on C-14 within BIOPROTA have been ongoing since 2005 when a review of C-14 models and concepts was published. This was followed in 2009 with a study aimed at building confidence through model-model inter-comparisons to develop understanding of why processes are, or are not, included in different models. Even with a well-defined scenario, a large variation in C-14 model output can be observed, but this may be explained by the parameterisation of the different models. The focus was on soil-plant systems. In 2010, a workshop was held to discuss C-14 research programmes and to share understanding around processes of importance for C-14 modelling. This was followed in 2011 with an extension to the 2009 work programme on model inter-comparisons. Two scenarios were considered and results from models were again variable. The sensitivity of some models to parameters was investigated by varying the parameterisation where there were known uncertainties. Together, the model comparison work programmes led to a convergence around the important processes for C-14 in soil-plant systems and their representation.

Several further workshops were held between 2013 and 2015 that extended C-14 considerations beyond soil-plant systems to also consider aquatic systems and whole ecosystem approaches to evaluating C-14 behaviour in assessments. Research programmes were also discussed, including research sponsored by RWM on methane oxidation in soils and uptake into plants and measurements of C-14 undertaken by IRSN for different environmental compartments (air, soil, grass) in the vicinity of the Cape de la Hague reprocessing plant in France. Datasets from these and other research programmes formed the basis of model-data inter-comparison exercises in a 2016-17 work programme that also included a review of carbon behaviour in lakes and uptake into fish. A key finding of this review was that the terrestrial environment can be a significant source of carbon to lakes. As such, the use of specific-activity models focussed on lake systems may result in a significant overestimate of dose.

The most recent activity relating to C-14 was a workshop that was held in spring 2019 that aimed to take stock of progress in addressing C-14 uncertainties in assessments and to present and discuss recent research and model/assessment developments. Whilst significant progress has been made, there continue to be issues in assessing C-14. The appropriate approach to take in modelling C-14 must be informed by the assessment context, taking appropriate account of temporal and spatial averaging and understanding of carbon pools. There also remains scope for further studies relating to aquatic systems, such as furthering understanding of carbon uptake to fish and other biota in rivers and marine systems.

Suggestions for next steps are being developed as a result of this most recent workshop, including the potential for new data sets to be identified that would allow further model-data comparisons, potentially extending to aquatic systems. There is also scope for a monograph on C-14 to be prepared that covers all the work undertaken within BIOPROTA to-date, as well as other work programmes. Clemson University has offered this as a potential work programme for a post-graduate student.

3.4.2 Selenium-79 in soils and uptake into plants

Karen Smith (BIOPROTA Technical Secretariat) presented.

Selenium occurs naturally in the environment and is an essential micronutrient with uptake into plants being an important dietary source. Selenium can also be toxic with only a narrow range between deficient and toxic concentrations. It displays complex environmental behaviour, potentially being present in multiple forms depending on redox conditions, with the form(s) present affecting mobility and bioavailability, which may help to explain the three order of magnitude range in Kd values reported in literature.

Selenium-79 has been shown to be of potential radiological significance in various studies relating to the disposal of solid radioactive waste. A three-phase BIOPROTA programme has been undertaken on Se-79, relating to selenium in soils and uptake into plants. A workshop was initially held in 2008, aimed at identifying the key attributes of Se-79 relevant to long-term radiological assessment. This was followed by a more detailed review of environmental behaviour, analysis of FEPs, development of an interaction matrix and review of different modelling approaches, including some developed following the initial phases, in 2009-2010. A model inter-comparison exercise was then undertaken between 2010 and 2012 that considered a hypothetical release scenario as a means of exploring the significance of different models and data assumptions and the degree of model complexity required for evaluating Se-79 behaviour in soils and uptake into plants. It was concluded from the various stages that understanding of speciation is key to modelling Se-79 in soils and uptake into plants. The application of more process-based models may help to reduce the importance of Se-79 in assessments.

No work has, as yet, been undertaken with regard to the uptake of Se-79 by animals.

3.4.3 The behaviour of radium and uranium in the environment

Mike Thorne (Mike Thorne & Associates) presented.

Radium

A workshop on radium in the environment was held in May 2010 at which a wide range of presentations were given on topics including effects of phosphogypsum amendments in agricultural soils, environmental behaviour of Ra-226 in aquatic and terrestrial systems, radiological characteristics of legacy sites, radium sorption to soils, the behaviour of radium and its progeny in animals and interactions between radium and both calcium and barium. Various aspects of radium in assessment programmes were also covered and data gaps and uncertainties identified. These included a lack of data relating to the accumulation of radium in soils and sediments and especially in clay and organic substrates, the potential for environmental change to affect mobility, high variability in the transfer of radium to crops, and the potential for concrete use in near-surface facilities to affect interactions between calcium and radium. A report of the workshop is available from www.bioprota.org.

The IAEA has also published a report on radium (TRS 476) that covers the properties of radium, radium in the environment, environmental pathways and corresponding models, dose assessment, mitigation and remediation issues plus case studies. A similar technical report has been produced on polonium (TRS 484). Research requirements for radium include the following.

- Investigate factors driving observed differences in soil to plant uptake.
- Apply analogue elements to address gaps and uncertainties in the fate of radium in soil-plant systems.
- Review correlations between environmental concentrations of radium and concentrations in human organs and tissues, including teeth.
- Identify the key organic matter functional groups controlling radium behaviour in soils to support effective Kd determinations.
- Analyse clay soil profiles to identify soil gradients that may affect radium behaviour in soils above near-surface disposal facilities.
- Investigate the effect on dose calculations of including multiple soil layers to represent root distributions in soils.
- Review Biosphere Dose Conversion Factors for different sites to identify features and processes driving differences in results at a site-specific level.
- Investigate minimum containment requirements for near-surface disposal facilities that meet human and environmental safety criteria.
- Investigate the effects of climatic and environmental changes on the containment of radium in clays and mobility in soils for typical ecosystems.

Uranium

A BIOPROTA project report on improving confidence in long-term dose assessments for U-238 series radionuclides was published in 2012. The project involved a model comparison of conventional radionuclide transport models with one or two compartments with more complex multi-layer soil models that allowed changing redox conditions to be evaluated. The models were applied to a case based on real information collected from Los Ratones, a former uranium mine site in the south of Spain. The aim was to estimate radionuclide concentrations in the soil and crops occurring as a result of migration of the radionuclides up through the soil profile. The simulation period was 47 years. Calculated potential radionuclide concentrations in soil and plants varied between models by around one order of magnitude. Results indicated that U-238, U-234, Th-230 and Ra-226 move at different speeds through the soil column.

An IAEA report on uranium has recently been developed that goes further than the biosphere, including topics such as the history and uses of uranium, physical and chemical properties, distribution in the environment, environmental transfer data and principles for radiological and toxicity assessments for which equal weighting is given to humans and biota. In terms of distribution in the environment, the report is data rich, pulling together information from a wide range of sources and for varied locations. Transport of uranium on a catchment scale is included. Case studies are given in relation to legacy sites and the phosphate industry and remediation is discussed. Extensive data on the behaviour of radium and uranium in the environment are provided that can be interpreted by models of different degrees of complexity. The report is in the process of being published.

3.4.4 Special interest in Cl-36

Russell Walke (BIOPROTA Technical Secretariat) presented.

BIOPROTA work on Cl-36 began in 2006 with a workshop that was followed in 2008-2009 with a two-phase model inter-comparison exercise. The first phase was focussed on Cl-36 in soils and uptake into plants. Phase two then extended considerations through to dose assessments.

Chlorine-36 is an important radionuclide in many post-closure safety assessments, is an essential element for plants and animals, and is subject to homeostatic control. The behaviour of Cl-36 is dependent on the level of stable chlorine and the form in which it is present. Typically, chlorine is present as chloride, which is mobile. Organic forms are less mobile and more persistent.

Conventional models for Cl-36 assume instantaneous equilibrium soil-water distribution coefficients and concentration ratios or transfer factors for uptake by animals. Parameters can be modified to account for different levels of stable chlorine present in the environment. Alternatively, a specific-activity approach can be adopted or a more process-based approach can be applied that considers the flows and fluxes of matter within a system. All three types of model featured in the model-comparison exercise, the objectives of which were to undertake illustrative calculations using the different models and, from this, to consider recommendations for dose assessment for long-term post-closure assessment.

In phase one, both irrigation and groundwater upwelling sources were considered and, for each source, uptake into a variety of crops was considered. The range in model output for cereals was greater than for other crops. The location of crop production relative to the coast also affected output with crops grown in coastal locations having a lower Cl-36 uptake as compared with inland locations due to a greater concentration of stable chlorine being present. In terms of the model types, conventional models were found to give lower results as compared with specific activity models. The more process-orientated models fell within the range between conventional and specific activity models. the concentration of Cl-36 in plants increased with Kd and irrigation rate.

Phase two considered the same crops, but with uptake into agricultural animals and humans being considered within a single irrigation scenario. Models typically equilibrated within 30 years. Variation in the contributory exposure pathways and foodstuffs was observed even though it was a relatively prescribed scenario. Calculated doses were typically within a factor of fifteen, irrespective of the type of model and its parameterisation. The modelling of soil-to-plant transfer dominated the uncertainties. It was concluded that, if using a Kd and CR based approach, a distinction should be made between areas with high and low natural (stable) chlorine values.

Based on the comparison exercises, it was recommended that, where there is a specific site, consideration should be given to location relative to the coast when deciding on the appropriate modelling approach. Data on foliar uptake of chlorine was noted as limited. However, since the conclusion of the chlorine work programme there have been further studies on Cl-36 including some foliar uptake studies in the Chernobyl exclusion zone.

4. CURRENT BIOPROTA WORK PROGRAMMES AND FUTURE PROJECTS

Progress with ongoing BIOPROTA projects was presented prior to presentation and discussion around possible future activities.

Ideas for future work programmes are invited to be submitted at any time by member organisations. These could be for future workshops on topical issues or projects around model-model or model-data comparisons or for reviews on particular subjects. Proposals should include details of the proposed technical support team plus requested budget with project plans then being updated to reflect resources offered.

Summaries of presentations and discussion are provided below.

4.1 PROGRESS WITH BIOPROTA ACTIVITIES

4.1.1 Towards a proportionate approach to radioactive and chemical hazards in radioactive wastes

Graham Smith (GMS Abingdon) presented.

The BIOPROTA programme on a proportionate approach to radioactive and chemical hazards in radioactive wastes began in 2014 with a workshop[i] that was held in Slovenia that was aimed at discussing issues around the topic, rather than trying to identify some sort of solution. It was clear from that workshop that more discussion was needed between the different communities concerned with hazardous waste disposal, NORM management and disposal, and post-disposal safety for radioactive waste. The issues are very challenging, especially if multi-stressors are considered. The issues are made more complex by differing terminology that can be used between the various assessment groups.

A follow-up workshop was held in Norway in 2015[j] that was more focussed on comparing the different safety and environmental impact assessment approaches for radioactive and hazardous waste disposal and, specifically, protection objectives and regulatory requirements. The science, management strategies and regulations for radioactive and hazardous materials have developed separately and, as such, differences are notable. For example, for hazardous waste disposal there is a focus on controlled release of leachate to ensure benchmarks are not exceeded, whereas for radioactive waste disposal the focus is on containment to allow for radioactive decay. Timescales for assessments also differ with those for hazardous wastes being considerably less than for radioactive wastes. Furthermore, safety indicators and criteria are not always consistent in terms of protection quantities and the level of protection afforded. Such differences could give rise to disproportionate risk management and resource allocation.

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[i] BIOPROTA (2014). Scientific basis for long-term radiological and hazardous waste disposal assessments. Report of an International Workshop, Version 2, 7 January 2014. Available from www.bioprota.org.

[j] Workshop report published as NRPA report 2015:8 (https://www.dsa.no/en/publications)

A BIOPROTA project was set-up following the second workshop to study the issues affecting the assessment of impacts of disposal of radioactive and hazardous waste[k]. The report from that project has sections on:

- objectives and derived criteria for environmental and human health protection;
- review of assessment methods and data requirements for non-radiological assessments of waste disposal;
- review of the content and application of groundwater protection legislation as applied to waste disposal facilities;
- review of the design and use of toxicity indices; and,
- identification of factors to consider in the design of effective assessments.

Appendices include an illustration of assessment of chemical alongside radiological impacts and a consideration of synergistic effects.

The report concluded that (i) there is real difficulty in fitting mixed hazards into current management schemes and regulatory regimes, and (ii) ensuring an appropriate and proportionate level of environmental protection from radiological and hazardous components of waste is both hard to deliver and to communicate. As such, it was recommended that the focus of assessments should be on risk rather than dose and that typical standards for hazardous waste should be applied to the management and assessment of radioactive waste with consistent assessment approaches and models being applied (e.g. to the release and transport of contaminants), where appropriate. Several challenges were also identified, including the application of groundwater protection legislation, e.g. under the European GWD, to radioactive waste repositories and the feasibility of developing a single toxicity index addressing chemical and radiation hazards associated with solid waste on a consistent and equitable basis.

A suggestion for a next step was to investigate the scope for a method that would support decisions on whether wastes should be managed primarily as hazardous with some radiological protection additions, or as radioactive waste with some hazardous materials protection additions.

There are several other working groups interested in this topic and there is therefore scope to draw together interested parties to discuss further within a workshop environment: there is a real and urgent need for a proportionate approach and further discussions across the different interested parties may help in developing such an approach.

4.1.2 BIOMASS methodology: progress and forward plans

Russell Walke (BIOPROTA project Technical Support Team) presented.

The IAEA BIOMASS methodology was developed between 1996 and 2001 and is a widely accepted methodology for biosphere assessment. Whilst those undertaking assessments may not follow the prescriptive steps of the methodology, the workflow is recognised as useful in providing structure to

[k] Project report published as NRPA report 2018:6 (https://www.dsa.no/en/publications)

assessments as well as being useful in helping gain confidence that important aspects of assessments have not been missed.

Since 2001, there have been considerable developments both in terms of knowledge gained from undertaking assessments (e.g. experience in site-specific assessments, including assimilating site data into long-term assessment models) as well as scientific developments, such as the ability to model climate, undertake assessments of impacts on non-human biota, and the mathematical representation of processes. There has also been experience gained through the regulatory review of assessments. A BIOPROTA project was therefore established in 2016 that aimed to review and enhance the BIOMASS methodology to account for new knowledge and experience. The project is being run in parallel to working group 6 (WG6) of the IAEA MODARIA II programme that has consistent objectives, with the BIOPROTA project providing technical effort to support WG6 through to the completion of the final report that is due by the end of 2019.

Biannual workshops have taken place since the outset with each being accompanied by a workshop report. A draft report deliverable was delivered in 2017 that has subsequently been updated to account for feedback from project sponsors prior to wider distribution throughout BIOPROTA and WG6 participants to invite comments and feedback.

Funding is in place to allow continued technical support in 2019. Feedback from a range of participants was taken into account in early 2019 in a revised version of the report that was also updated to reflect the IAEA referencing system and included some additional text. The updated report was distributed in early May as the basis for discussions at the first 2019 workshop (held following the annual BIOPROTA meeting). A report of that workshop will be prepared and the draft final project report is due to be delivered prior to the final technical meeting in October 2019. The draft final report will address remaining data gaps and include a range of examples to support different aspects of the methodology. The 2019 funding will also provide for technical support and reporting of the final technical meeting during which the final report will be delivered.

Additional feedback on the draft report is encouraged, particularly from those new to the field to ensure that the report is clear and logical and covers all areas of interest at an appropriate level.

4.2 POTENTIAL FUTURE COLLABORATIVE WORK

4.2.1 Bioavailable CR's and Kd's

Lauri Parviainen (Posiva) presented.

Posiva has collected an extensive dataset as a result of the Olkiluoto site monitoring programme, including bioavailable element data. These data have not yet been used in Posiva's assessment programme, but there is interest in considering how best they might be used.

Concentration ratios are largely derived based on total element concentrations in soil, but uptake of elements by plants is more appropriately assessed when evaluated in relation to bioavailable concentrations; the use of total element concentrations may be pessimistic.

There are various sample treatments that can be employed in measuring bioavailable concentrations. Posiva has used ammonium acetate extraction. It is recognised, however, that different methods may be more suitable for some elements than for others.

Bioavailable concentrations are smaller than total element concentrations in soils. This gives rise to lower Kd values, but larger CR's. For some elements there are considerable differences in parameter values derived based on bioavailable rather than total element soil concentrations.

A project is therefore proposed around the topic of CR and Kd values derived on the basis of bioavailable versus total element soil concentrations, to consider for which elements the use of bioavailable-based data could be considered more appropriate (e.g. for the more mobile elements). As an initial stage, a workshop is proposed, potentially being held in autumn 2020 in Finland. There is already potential interest from researchers at the University of Eastern Finland that are involved in independent radioecological studies on the long-term safety of nuclear waste repositories. Posiva could also undertake some probabilistic modelling by that time using bioavailable data with results being discussed during the workshop. The appropriate extraction techniques for elements could also be discussed.

Discussion

It can be challenging to demonstrate the best extraction approach for demonstrating bioavailability of different elements in soils, with extraction depending on the chemical properties of elements. Furthermore, for elements that are taken up by plant roots by passive uptake, analysis of element concentrations in soil water would be appropriate, but for elements that are actively transported, roots may be able to extract more than what is contained in the pore water alone. However, many extraction techniques are aggressive and will not give rise to results that are realistic in terms of what plants can access.

There is a considerable scientific literature on extraction techniques, and it would make sense to look into this as input to any work programme. Whether bioavailable or total element concentrations are used in deriving CR and Kd data could have important implications for assessment programmes, but could help narrow the range in parameter values and increase confidence in assessments.

4.2.2 Discussion of topics for future/continued collaboration

Carbon-14 is an ongoing area of collaborative work with a workshop having recently taken place. There remains scope for further collaboration, with continued interest in both wetland and aquatic ecosystems. For aquatic systems there is interest in whether improved representation of C-14 behaviour can be achieved through improved understanding of carbon dynamics in aquatic systems. There is also interest in identifying whether there are potentially useful data sets (e.g. river discharges and fish monitoring) that could form the basis for model-data comparison exercises. Based on discussions at the most recent C-14 workshop, a proposal will be developed. There is also interest in collating together the current information relating to C-14 in a monograph, with Clemson University having offered to undertake this task. Other areas of interest with regard to C-14 include:

- The potential to exploit new knowledge and data arising from stable carbon research programmes (e.g. peat and climate research groups).
- Evaluating whether root exudation should be included in models as a means by which plants can return carbon to soils.
- Reviewing studies from Sweden and Finland (plus elsewhere) on carbon cycling in different systems to develop summaries of carbon behaviour.

Chlorine-36 has not been considered specifically within BIOPROTA for several years and there is potential scope for further work, particularly model-data comparisons if suitable data sets are identified. Andra and EdF aim to publish as much information as possible, including measurements, from their recent collaborative work on Cl-36 (see Section 3.2). This could be useful in developing a further work programme within BIOPROTA potentially in 2020/2021, with initial discussion around the data set during the 2020 annual meeting.

IAEA publications give substantial compilations of data and knowledge around **uranium series radionuclides**, but do not go as far as how to model within an assessment context. Nonetheless, models could be informed by the available data sets, which may provide potential for modelling exercises. Thought needs to be given, however, as to what would be useful in terms of a modelling exercise, since it is disequilibrium in the decay chain throughout the whole repository system that matters the most. Data from uranium legacy sites, as whole systems, could therefore be useful.

The topic of **other radionuclides of importance** should be revisited in future meetings to ensure continued focus on what matters most. **Non-radioactive hazards associated with radioactive waste** continues to be a topic of interest and there may be merit in looking in more depth at decommissioning wastes to identify the radiological and chemical components of most interest that could become issue topics in the future.

The topic of developing a **proportionate approach to radioactive and chemical hazards in radioactive wastes** continues to be of interest and ideas are invited to help shape the next stage of work. A list of possible interest areas will be developed and member organisations will be invited to respond on which are the main areas of interest with those main interests informing proposal development. The enhanced **BIOMASS methodology** is being written carefully to refer to contaminants rather than radionuclides so that is should be equally applicable to radioactive and chemical hazards. The method does not, however, go so far as to explicitly consider application to chemical hazards and evaluate whether the use of one biosphere model for the different hazards is appropriate. A stand-alone project within BIOPROTA could consider how the method applies to chemicals, but the scope for such a project would need to take account of the potentially different receptors: in the UK it is concentrations of chemical hazards at compliance points in groundwater that is evaluated rather than biosphere modelling being undertaken, whereas in France it is human receptors that are evaluated.

Assessments require some sort of **inventory screening** to identify the radionuclides of significance. Different approaches to screening could be compared in a project, covering screening of both radionuclides and hazardous chemicals in associated with decommissioning wastes.

A number of new **radionuclides of particular interest** were identified (see Table 3) and it may be worthwhile discussing these in more detail during focussed workshops, potentially holding different sessions to discuss multiple radionuclides within one extended workshop. Briefing notes could be prepared in advance on known behaviour such as mobility and accumulation in the environment, along with questions (e.g. reasons for interest, how to assess, data availability etc.) to inform discussions. The briefing notes on each radionuclide could then be updated following the workshop, summarising behaviour and supporting data. A similar approach could be taken for non-radioactive materials, but with experts from the non-radiological field (e.g. SETAC) being invited to participate. The IUR Forum could be a good means by which SETAC could be engaged.

Several member organisations have **models for forest ecosystems**. The transferability of such models to different environments could be investigated and/or a comparison of the different models undertaken. A particular focus could be the modelling of element cycling in forests where element transfer is coupled to the hydrological regime. It is intended that a database of parameters from the Mol forest station in Belgium will be developed that will be made publicly available. This could form the basis for a forest modelling task when available. A catalogue of other potential data sets could also be developed, detailing the range of data encompassed. There may be merit in considering a semi-natural ecosystems working group within a MODARIA III programme that could be supported by BIOPROTA.

5. FORUM ARRANGEMENTS FOR 2019-20

Forum arrangements for 2019-20 are set out below, along with feedback from the 2019 Sponsoring Committee meeting.

5.1 FEEDBACK FROM THE SPONSORING COMMITTEE MEETING

Potential new members to the forum, both full paying members and academic members, are to be invited to present during annual meetings to inform on interest areas.

The status of the different levels of membership are to be made clearer. Paying members are automatically part of the sponsoring committee. Academic members do not pay a fee and, therefore, do not form part of the sponsoring committee. KTH Royal Institute of Technology is proposed as a new academic member.

Interest was expressed for project proposals to be developed in relation to:

- further work on C-14;
- biosphere modelling codes;
- environmental monitoring and baseline samples; and,
- bioavailable CR and Kd values (as presented in Section 4.2).

There is also scope for further work in relation to moving towards a proportionate approach to radioactive and chemical hazards in radioactive wastes, with some funding already in place. New project proposals can be submitted at any time and will be distributed by the technical secretariat. The work programmes are managed independently of the technical secretariat and there is no requirement for the technical secretariat to be involved as part of project technical support teams.

A report numbering system is proposed for BIOPROTA publications, potentially with ISBN numbers being assigned to allow publications to be included in international databases. A revision to the forum website was also proposed, removing the need to register to the site in order to gain access to the publications.

5.2 FORUM ARRANGEMENTS IN 2019-20

Alexander Diener from BfS will continue to chair the forum in 2019-20 with the 2020 annual meeting being hosted by SURAO in Prague. There remains interest in the annual meeting including a topical session. Suggestions for topics for the 2020 meeting are invited.

APPENDIX A. 2019 MEETING PARTICIPANTS

Participant	Organisation	Country
Geert Biermans	FANC	Belgium
Maryna Surkova	FANC	Belgium
Jordi Vives i Batlle	SCK·CEN	Belgium
Zdena Lahodová	SURAO	Czech Republic
Hana Hustakova	UJV	Czech Republic
Ari Ikonen	EnviroCase (for SKB)	Finland
Lauri Parviainen	Posiva	Finland
Emilie Aubonnet	Andra	France
Lise Griffault-Sellinger	Andra	France
Yves Thiry	Andra	France
Laura Milelli	EdF	France
Taku Tanaka	EdF	France
Alexander Diener	BfS	Germany
Martin Steiner	BfS	Germany
Manuel Claus	Öko-Institut	Germany
Veronika Ustohalova	Öko-Institut	Germany
Yukiko Fukaya	Janus (part of JGC)	Japan
Donghee Lee	KORAD	Korea
Olle Hjerne	SKB	Sweden
Ulrik Kautsky	SKB	Sweden
Maria Norden	SSM	Sweden
Shulan Xu	Xu Environmental Consulting (for SSM)	Sweden
Jürgen Hansmann	ENSI	Switzerland
Priska Hunkeler	Nagra	Switzerland
Graham Smith	GMS Abingdon	UK
James Ridehalgh	LLWR	UK
Mike Thorne	Mike Thorne & Associates	UK
Russell Walke	Quintessa (BIOPROTA technical secretariat)	UK
Karen Smith	RadEcol Consulting (BIOPROTA technical secretariat)	UK
Ray Kowe	RWM	UK