BIOPROTA

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

Report of the 2018 BIOPROTA Annual Meeting

Kerava, Finland
14-15 May 2018

Version 2.0, Final
11 September 2018

PREFACE

BIOPROTA is a forum for international collaboration 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 general objectives of BIOPROTA are 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 required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities. The programme of activities is driven by 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 twentieth BIOPROTA annual meeting held 14-15 May 2018. The meeting was hosted by the Posiva in Kerava, Finland. 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 17 July 2018.

Version 2.0: Final meeting 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 11 September 2018.

CONTENTS

1. INTRODUCTION

The twentieth BIOPROTA meeting was hosted by Posiva in Kerava (near Helsinki), Finland, 14-15 May 2018. The support of Posiva in the organisation and hosting of the meeting is gratefully acknowledged.

There has been a long history of international collaboration relating to biosphere assessments where common challenges have been identified. Some programmes have been run through international organisations such as the International Atomic Energy Agency (IAEA) or European Commission (EC) whilst others have been independent of such organisations, as is the case for BIOPROTA.

The BIOPROTA forum aims to provide a flexible platform for discussing biosphere assessments and to identify common issues in biosphere programmes for which a collaborative effort may be beneficial in addressing those challenges. The forum was set up in 2002, following the completion of the IAEA BIOMASS programme in 2001. The scope of the forum is defined in a Concept and Definition document that shows how the forum works administratively and provides an overview of the work programme. This is a key document for the forum and is updated annually; the latest version was updated in December 2017 and distributed to all members of the forum.

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 (TS) 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.

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 TS, 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. In 2017 sponsoring members were as follows:

- ANDRA, France
- ARAO, Slovenia
- AREVA, France
- BfS, Germany
- EDF, France
- ENSI, Switzerland
- FANC, Belgium
- FMBC, Russia
- KORAD, Korea
- LLWR, UK
- NAGRA, Switzerland
- NRPA, Norway
- NUMO, Japan
- NWMO, Canada
- POSIVA, Finland
- RWM, UK

- IRSN, France
- JGC Corporation, Japan
- KAERI, Korea
- SCK·CEN, Belgium
- SKB, Sweden
- SSM, Sweden

The academic members in 2017 were:

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

At the time of the 2018 annual meeting, membership invitations had been distributed to all current members. In addition, two new full members were welcomed (SURAO and UJV, both from Czech Republic) and one new academic member (Clemson University, USA). The US EPA (USA) has also been invited as a full 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 solid 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.

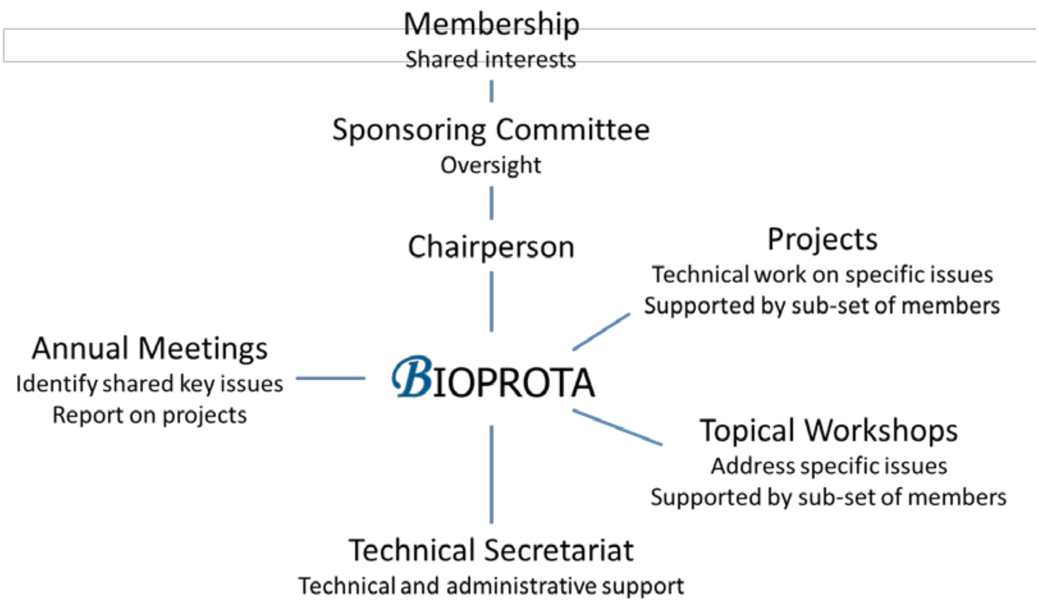

Figure 1. Structure of the BIOPROTA forum.

The Sponsoring Committee is headed by a chairperson who is elected each year during the annual BIOPROTA meeting. The chairperson in 2017 was Lauri Parviainen from Posiva.

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 TS 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 in the fifteen years that BIOPROTA has been running.

1.1 OBJECTIVES AND SCOPE OF THE MEETING

The primary objective of the annual BIOPROTA meetings are to provide an opportunity for members to come together and discuss issues of commonality. The meeting was therefore structured to support the exchange of information and experience relating to biosphere assessment programmes and the output of BIOPROTA projects since the 2017 annual meeting, and to identify and discuss ideas for future projects. The following sessions were held:

- Session 1: Progress and perspectives for the future from member organisations.
- Session 2: Environmental monitoring programmes and preservation of baseline samples for the future.
- Session 3: Current work programmes and forward plans.
- Session 4: Future projects and other international developments.
- Session 5: Summary and forum arrangements for 2018/19.

1.2 PARTICIPATION

The meeting was attended by 34 participants from 13 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 environmental monitoring programmes and preservation of baseline samples for the future. An overview of current BIOPROTA work activities and future projects is then provided in Section 4 with forum arrangements in 2018-19 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 CURRENT STATUS OF POSIVA'S PROGRAMME FOR SPENT NUCLEAR FUEL DISPOSAL

Lauri Parviainen presented on behalf of Posiva.

2018 marks 40 years of effort in Finland on the disposal concept for spent nuclear fuel (SNF) with the first studies into geological disposal having begun in 1978. Site selection research took place through the 1980's and 1990's with the result that, in 2000, Olkiluoto Island was selected as the site for the disposal of SNF, which was confirmed through a Decision in Principle in 2000 by the Finnish Government that was ratified by Parliament in 2001. Following the Decision in Principle, site investigations were undertaken and an underground research facility (ONKALO) was constructed. The site investigations and ONKALO facility were to help generate appropriate site understanding and site data for a construction license application, which was submitted by Posiva in 2012 and granted by the Governmentin 2015. This license allowed the disposal facility to be constructed through extension of the ONKALO facility. An application for an operating license is due to be submitted in 2021 with the first disposals anticipated in the following years.

With the construction license having been granted, a full scale in-situ system test (FISTT) is planned. This will take place in a tunnel at 437m depth. The test will consist of two full-sized copper canisters containing internal heaters emplaced in vertical disposal holes with bentonite backfill (Figure 2). Monitoring devices will be installed to allow temperature and pressure etc. to be measured over time. It is intended that, after some as yet undefined time (likely some decades), the FISTT will be opened to allow further study of the canisters and surrounding bentonite.

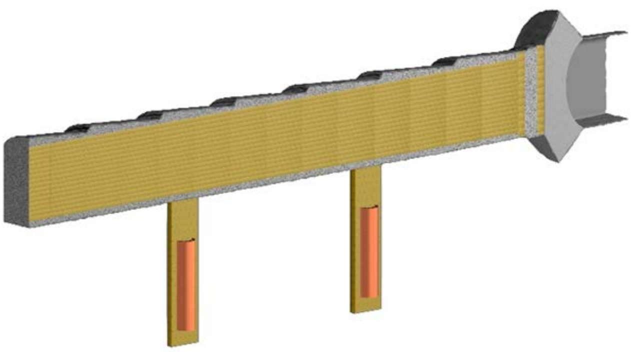

Figure 2. Illustration of the placement of copper canisters (orange) and bentonite backfill (yellow) within the planned FISTT.

Work on the construction of an encapsulation plant at the site is currently ongoing with groundworks underway. Construction of the encapsulation facility itself is planned for 2019. Repository excavations are also progressing, as illustrated in Figure 3. Three of four disposal shafts have been completed with the fourth currently being bored. The shafts will provide the means by which canisters can be lowered into the repository.

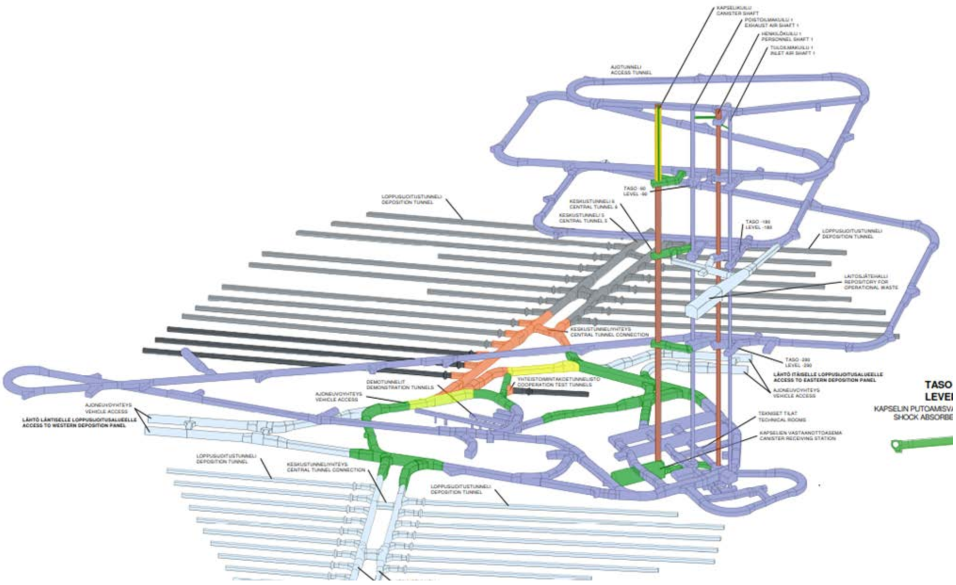

Figure 3. Excavation of the Olkiluoto repository. Purple and green illustrate completed excavations. Darker grey indicates where construction has recently begun.

Work in support of the 2021 operating license submission (OLA-2021) continues to progress with much due to be completed in 2018-19, including formulation of scenarios, initial state (covering the site and repository to the point when tunnels are sealed), design basis and site description (including biosphere description). Reports on the repository releases and dose assessment are due to be completed by the end of 2020. Work on modelling the discrete fracture network that will support radionuclide transport calculations is almost complete and hydrological and hydrogeochemical evolution modelling will then progress; these will ultimately support transport and dose calculations in the biosphere.

New features have been implemented to support the safety case as compared with the 2012 construction license safety assessment (TURVA-2012). For example, a safety assessment database has been developed that will host all assessment data. A contents management system will also be used to publish safety reports on the internet and will be supported by interactive flow charts to assist in navigating through the reports. A particular challenge to the development of the OLA-2021 submission has been the optimisation of the design concept that has delayed the planned design freeze.

In terms of the biosphere assessment for the OLA safety case (SC-OLA), FEP (features, events and processes) screening has been completed. Important FEPs include:

- climate evolution and land uplift (sea level, crustal uplift);
- sedimentation and terrestrialisation;
- agriculture (e.g. crop allocation, husbandry, irrigation, land use, forest and peatland management); and,
- drainage and wells.

SC-OLA will include more probabilistic modelling than BSA-2012, with probability distribution functions (pdfs) being required for the majority of transport parameters, including concentration ratios, partitioning coefficients, biomass and consumption rates. The landscape model will be run for a 10,000 year assessment time frame with a simplified biosphere model then being used for a period of 1 million years.

There have been a number of challenges faced. These have included difficulties in upscaling of the design concept (laying of bentonite is a slow process and alternative means are therefore being investigated such as use of bentonite pellets or blocks for tunnels and/or use of alternative equipment). The criteria for locating tunnels and deposition holes have also been updated to maximise efficiency of disposal whilst retaining long-term safety. Resource planning for the operational period has also been a challenge.

Discussion

The potential for fractures in bentonite as a result of compaction was questioned. The use of bentonite pellets is planned to ensure that the bentonite can be pushed into the tunnel and provide sufficient density and swelling capacity to prevent fracture issues. Furthermore, the FISTT is intended to obtain information on how the system behaves under realistic test conditions with instrumentation informing on whether the system is performing in line with expectations. This will include information on the behaviour of the bentonite backfill in terms of saturation and swelling pressure. The results of the FISTT will be communicated in reports that will be publicly available.

2.2 RECENT ACTIVITIES RELATED TO BIOSPHERE MODELLING AT BFS

Alexander Diener presented on behalf of BfS.

Germany has recently, and for the first time, revised the national regulations “AVV Tätigkeiten” that set out requirements for modelling the exposure of members of the public to ionising radiation. The initial version of the regulations was aimed solely at nuclear power plants, but the revision expands the scope to all companies permitted to use ionising radiation or monitor residues, and covers both prospective and retrospective biosphere assessment requirements. The revised regulations are currently in draft form and are being reviewed by the relevant Commissions, such as the Ministry of Environment. The scope of the regulations does not extend to long-term safety analysis, exposure of workers or the calculation of exemption limits or release values.

The AVV Tätigkeiten regulations are structured is as follows:

- Application field;
- Goals and principles of the radiation exposure calculation;
- Sources of radiation exposure;
- Dispersion of radioactive substances and environmental contamination by atmospheric discharge;
- Dispersion of radioactive substances and environmental contamination by fluvial discharge;
- Radiation exposure of the public by atmospheric discharge;
- Radiation exposure of the public by fluvial discharge;
- Radiation exposure of the public by ionising radiation from facilities; and
- Other pathways of public radiation exposure from contaminated soils.

The revised regulations stipulate the different exposure pathways that need to be considered in relation to atmospheric and fluvial discharges. For example, dose assessments for atmospheric discharges should consider exposure of members of the public to both beta and gamma radiation in the plume, inhalation, exposure to gamma radiation deposited on soils and ingestion exposure following uptake of radionuclides in agricultural produce. Assessment of the transfer of radionuclides to infants via breast milk (resulting from direct atmospheric uptake by the mother or from dietary uptake) is also required. For fluvial discharges, food and water consumption pathways are stipulated along with external pathways such as exposure to contaminated sediments.

Changes to the regulations that are of particular note are:

- Exposure of the public is treated in terms of representative persons, such that extreme or unrealistic behaviours should not be considered;
- Radiation exposure should be calculated as realistically as possible, but maintaining a degree of conservativism to avoid underestimation;
- The input data for annual dose calculations differ depending on whether a prospective or retrospective assessment is being undertaken with generic and measured (where available) data being used, respectively;
- There is a requirement to explicitly model exposure from direct radiation;
- Only annual effective dose needs to be assessed such that organ doses are no longer included;
- Exposure from multiple sources must be taken into account, along with accumulation of radionuclides in the environment;
- All possible uses of the environment should be included in prospective assessments whereas for retrospective assessments the dose resulting from actual utilisation should be evaluated;
- For atmospheric discharges there has been a change from the use of a Gaussian-Plume model to a Lagrangian-Particle model;
- For liquid effluent discharges, small lakes can now be modelled where previously only rivers were considered, and a new water dispersion model has been added along with a new assumption of no water withdrawal at the discharge point (100 m downstream of the discharge being the default value where no site-specific data is available); and,
- New exposure pathways have been included in relation to contaminated soils such that gamma irradiation from soil, inhalation of resuspended matter and soil ingestion should all be considered.

A key difference between prospective and retrospective assessments is that the focus for prospective assessments is to support decisions around discharge permits and to ensure no unacceptable detriment will occur whereas retrospective assessments are based, where possible, on measured values and there is an emphasis on ensuring that the dose assessment is as realistic as possible. As such, prospective assessments are more conservative.

The revised regulations stipulate spatial criteria for dose assessments. In terms of releases to air, a circular area around the source of 5 km radius or 50-times the emission height should be considered. For fluvial releases the whole surface water system and its environment downstream of the discharge is to be considered. For monitored residues, dust inhalation up to 100m from the residue area should be evaluated. Distances of 500 m and 100 m should be considered for direct radiation from nuclear facilities and other facilities, respectively.

With the exception of NORM a dose criterion of 10 µSv/y is applied (for NORM a dose criterion of 100 µSv/y is applied). However, where members of the public may be exposed to radiation from a number of sources, exposure from all sources should be evaluated and compared against a dose criterion of 100 µSv/y.

A new breast milk pathway model is included in the revised regulations. Previously a transfer factor approach from food or air to breast milk was applied. The new approach uses ICRP dose coefficients and both acute and chronic incorporation of radionuclides within the mother and subsequent transfer to breast milk. For chronic incorporation, consideration is given to the period from pregnancy through to the end of a 6 month nursing period.

For direct radiation exposure, attempts were made to find a useful and broadly applicable calculation method. This was difficult, however, due to the large number of cases that the method would need to be applicable to. As such, the regulations stipulate the need to calculate radiation fields with simulation methods (e.g. MCNP, SCALE, PENELOPE) for all areas accessible to members of the public, taking account of variables that influence exposure, such as the spatial distribution of radionuclides.

Since 2017, BfS has been comprised of two separate divisions: BfS and BfE (Bundesamt für kerntechnische Entsorgungssicherheit). The BfE division is the approval agency for nuclear fuel transport and nuclear fuel repositories. The current temporary storage locations for low level waste (LLW) and intermediate level waste (ILW) are in either hard or soft rock types and dose calculation methods have all been based on the AVV Tätigkeiten regulations. However, further regulations are needed on how the exposure of a representative person resulting from a high level waste (HLW) disposal facility should be calculated. BfS and BfE are cooperating on the development of such regulations, which will include biosphere modelling requirements. The starting point will be to consider the habits of potentially exposed groups (PEGs) and how climate change could impact on habits (e.g. changes to consumption rates, agricultural practices etc.) and there is interest in knowing whether there is general agreement on the degree to which climate may affect habits. This is a topic being discussed within the ongoing project to enhance the IAEA BIOMASS methodology.

The regulations around biosphere assessments for HLW disposal are due to be completed by the end of 2019.

Discussion

The regulations set out how public doses have to be modelled across the 16 German Federal States. It is not, therefore, up to operators to select the approach to be taken.

For NORM sites it is not yet a requirement to integrate assessments of radiation exposure with the exposure to non-radioactive hazardous substances. However, where such assessments are undertaken, models and approaches should be kept as consistent as possible.

2.3 WHAT IS HAPPENING AT SKB OVER THE NEXT DECADES?

Ulrik Kautsky presented on behalf of SKB.

A new research and development (R&D) plan is due to be submitted to the regulator (SSM) in September 2019. This will summarise R&D activities over the last 3 years and set out a plan for the forward 3 years. Such plans have to be regularly submitted and the approval of the last submission in

2016 has only recently been received. This was likely delayed to await the outcome from the Environmental Court on the license submission for the construction of a SNF repository at Forsmark. The license submission (SR-Site) was submitted in March 2011 and initial regulatory review comments were addressed prior to a hearing at the Environmental Court over a 3 week period in the autumn of 2017. One of the surprising points raised during the hearing was concern over copper corrosion rates, despite the high research investment on that topic, whereas greater focus on other environmental assessment aspects had been anticipated. The site selection and geological considerations were all judged to be acceptable, but the Court has made a recommendation to the Government that copper corrosion should be considered to a greater extent. A response from the Government is awaited, but with 2018 being an election year it is expected that any instructions will be delayed. As a result, SKB has re-prioritised the near-term work flow to account for being in a hold position on the SNF repository programme.

In addition to being the proposed site for SNF disposal, the Forsmark site is the location of an operational near-surface LLW disposal facility (SFR). The current facility is located at a depth of around 60m below the sea bed. However, SKB has recently submitted a safety assessment (SR-PSU) for an extension to the facility. This extension is planned to be at a depth of around 100m. The safety assessment is currently under review by SSM and SKB is therefore awaiting SSM's recommendations to the Government and the Environmental Court. It is likely that negotiations with the Environmental Court will take place toward the end of 2019.

The current focus area for SKB is therefore around a repository for long-lived ILW (SFL) and a concept study and preliminary safety evaluation are being progressed. There are some tricky radionuclides and other materials in the waste inventory to be disposed of in the SFL facility; disposal of decommissioning wastes from nuclear power plants and research wastes (containing liquids, mercury etc. in addition to radionuclides in a solid waste form) in drums previously intended to be sea-dumped is planned in this facility. With the mindset in the 1960's having been to dump drummed research wastes in the Baltic Sea, the documentation of drum contents is minimal. Furthermore, the drums themselves are now corroding. Much of this waste has now been repackaged and some analysis using probes has provided information as to contents, but some assumptions are still needed. Therefore, to avoid issues arising from the use of multiple pessimistic assumptions in safety assessments for this facility, careful consideration is being given to the selection of realistic assessment parameters where possible.

The waste to be disposed of in the SFL facility contains also a lot of historic uranium waste and radiotoxicity of the waste will persist over a much longer time as compared to the radiotoxicity associated with SFR. A more limited decline in radiotoxicity over time is also evident as compared with the repository for SNF.

In addition to work on the inventory and assessment parameter selection, new transport models are also being developed within Ecolego to allow integrated modelling throughout the entire system, from the waste in the facility through to the biosphere. A process-level model (Comsol) is also being applied to look at unsaturated flows in terms of streamlines of groundwater fluxes.

SKB relocated to new offices in May 2017 and has also recently restructured. For the first time, research and development (R&D) has its own division with both site investigation and monitoring falling within the remit of this division. The new division consists of around 140 personnel.

Discussion

Whether the assumption of only one canister failure in SR-Site would continue to be made under different copper corrosion rate assumptions was queried. The position of SKB is that the copper canisters provide a safe and robust disposal option and that corrosion rates are justified. Additional information in support of safety will be provided to the Government if requested.

2.4 OVERVIEW OF BIOSPHERE MODELLING FOR NEAR-SURFACE DISPOSAL FACILITIES IN KOREA

Donghee Lee presented on behalf of KORAD.

The Wolsong near-surface disposal site is located in a coastal region in the south east of Korea. It is sited in close proximity to operational nuclear power plants. The majority of waste to be disposed of in the facility is generated by these power plants, but waste from other sectors, including R&D will also be disposed.

The selection process for the site began in November 2005 with construction beginning in July 2008. Operation of the first phase of the facility began in August 2015. A second phase is currently in the licensing process and two further phases are in planning stages.

Biosphere modelling is being used to demonstrate compliance of the disposal facilities against performance objectives. The focus is on radionuclides and not on any associated chemicals in the waste. The biosphere model has been developed using GoldSim on the basis of the BIOMASS methodology.

The biosphere system has been described. The site is located in a mountainous area (over 70% of the region is mountainous) with some rivers present, as illustrated in Figure 4. The mountain on which the disposal site is located slopes gently down toward the coast. The rivers flow from the mountains to the coast without passing through the area of the disposal site itself, hence the rivers do not directly impact on the site. There has been site investigation together with research into local habits to inform on land use. Both fishing and farming are important in the area. Groundwater wells have also been used historically in the location of the site. Wells for drinking water abstraction and agricultural irrigation therefore require consideration in assessments. No climate change has been assumed in the assessments to date and current lifestyles are maintained.

Groundwater pathways have been modelled for both the first and second phases of the facility. In both instances, groundwater flows from the repository to the coast without any interaction with surface water, since there is no surface water present at the site. Groundwater will therefore flow to the marine system (Figure 5) unless a well is present that allows some groundwater to be directly extracted.

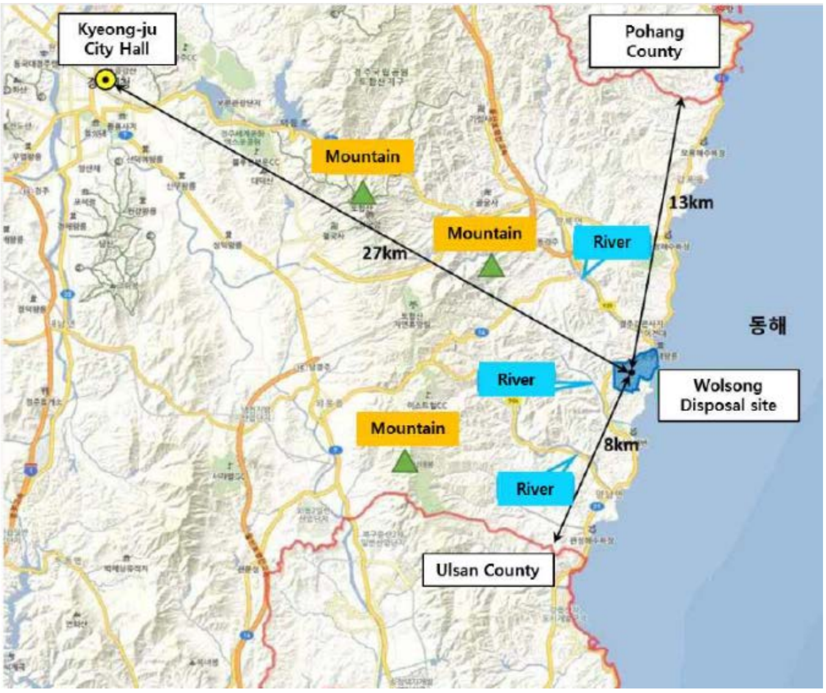

Figure 4. Location of the Wolsong disposal site, South East Korea.

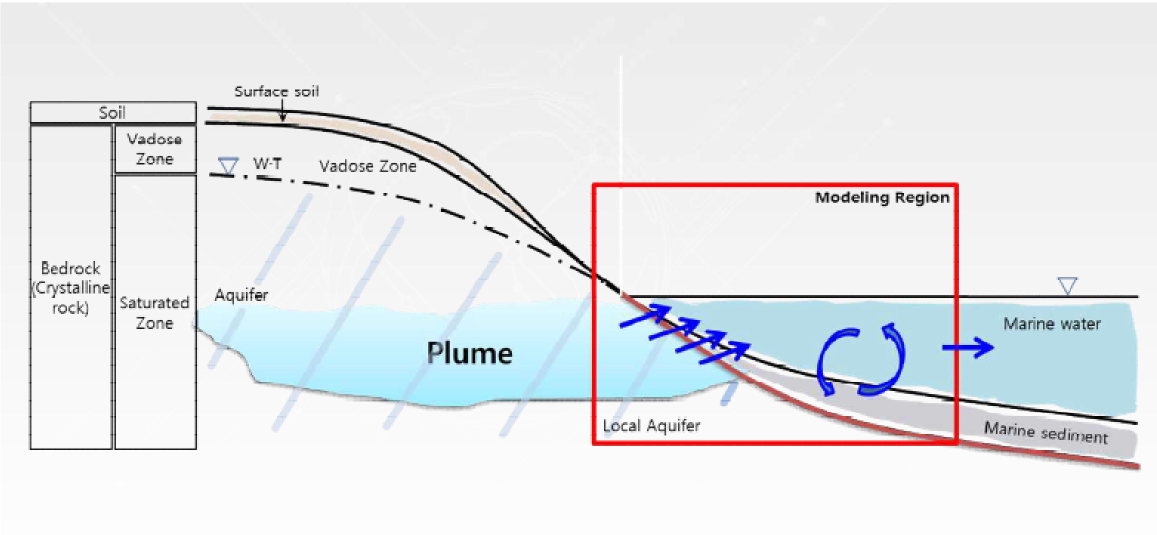

Figure 5. Cross-sectional diagram of groundwater flow and the interface between the geosphere and biosphere.

The exposure groups considered in the assessment for both phases are fishing groups and well-water drinking groups. A farming group has not yet been included, but is planned. For both fishing and drinking water exposure groups, external, inhalation and ingestion exposure pathways have been considered and dose conversion factors (DCFs) derived for each radionuclide based on a unit release rate assumption. Comparison of the DCFs for both exposure groups indicates that the well drinking water exposure group are the maximising case across all radionuclides.

In the next stages of the assessment programme, greater consideration will be given to different exposure groups, including farming. Further resources will be directed to the validation of the well scenario, since this gave rise to the greatest exposures in the assessments to date.

Discussion

The groundwater well scenario is the only intrusion scenario that has been considered to date and the national regulations require further improvements to be made around this scenario. If the construction of a well into the groundwater plume is considered to be likely, then it will be classed as a normal evolution scenario. If not, it will be classed as human intrusion. Surface erosion has not been considered. Similarly, shoreline and other biosphere changes, along with changes to groundwater levels, have not been considered, but may be in future assessments. Korea is a tectonically active area and it was noted that it may be appropriate to consider distinct, rapid uplift events (unlike for e.g. the Fennoscandian or Canadian Shield areas where the post-glacial uplift is mostly a continuous, creep-type phenomenon).

The first phase of the facility is located between 80 and 130 m below sea level and is planned to operate for a period of 60 years. A loss of performance is assumed for the concrete barriers at around 1,500 years. The second phase assumes that concrete performance will be maintained for 2,000 years. Waste is assumed to remain hazardous for 10,000 years and the model is run for 1 million years to capture peak releases. The first phase is designed for ILW whereas the second phase is for LLW.

2.5 DEVELOPMENT OF THE BIOSPHERE MODEL FOR THE DEEP GEOLOGICAL REPOSITORY IN CZECH REPUBLIC

Hana Hustakova presented on behalf of both SURAO and UJV. SURAO is the radioactive waste repository authority in Czech Republic and UJV is the Nuclear Research Institute.

The disposal concept for a deep geological repository in the Czech Republic is for direct disposal of spent fuel assemblies in a crystalline host rock, which is consistent with the KBS-3 concept, although canisters will consist of two robust layers – 1 carbon steel and 1 stainless steel. The same disposal site will be used for HLW and ILW, with sufficient distance to ensure that the two repositories are not mutually affected.

There are currently nine candidate sites under consideration. Preliminary safety case studies for each site are planned in 2018. These will be based primarily on archive data, with the intention of developing a better understanding of the issues in terms of safety, and allowing a comparison of the different candidate sites. It is intended that four of the nine sites will then be taken forward to the next stage in the process, which will involve the drilling of a limited number of deep boreholes at each site to derive data in support of further safety cases for each site. These safety cases, due in 2022, are intended to further inform on site selection and reduce the number of candidate sites to two. The two remaining sites will then be subject to further site investigation and more refined safety case studies to inform on the selection of a final site in 2025.

In 2016, a new Atomic Act was issued that came into force in 2017. This sets out the safety related legislative requirements for deep geological disposal in the Czech Republic. Annual effective dose to the representative person from the most exposed group is to be below 0.25 mSv under all possible FEPs that could occur during both operational and post-closure phases of the repository. The site is also required to be well characterised and understood in terms of its geology, hydrogeology, geomechanics and geochemistry. No geothermal sources can be present.

The main activities in support of the siting stage safety cases are to prepare site descriptive models, identify and allocate safety functions and requirements for safety-important components, identify FEPs relevant to the site and reference concept, undertake R&D activities to understand those FEPS, and prepare integrated safety assessment models. To achieve these activities, there are many experts across a range of different fields involved. In 2014, SURAO initiated a large-scale project involving a range of research organisations and universities. UJV is the lead contractor on this project. The project has included the development of biosphere assessment models.

Model development work began at UJV in 2003 with the GoldSim modelling code being used since 2006. The first local biosphere model developed within the SURAO project was for the Kravi Hora site in 2017-2018. This model has recently been applied to undertake deterministic calculations.

The project for the development of a local version of the biosphere model for the Kravi Hora site has required new features to be incorporated within the biosphere model, such as the transport of radionuclides to crops by foliar uptake and translocation, the addition of cereals for human consumption and as feed for pigs and poultry. The development of a special transport model for C-14 was also required.

A normal development scenario has been defined. This involves radionuclides being transported from the repository through a preferential pathway to a well that is used for both domestic and agricultural purposes by the local community. One of the reference biospheres within the IAEA BIOMASS methodology was the basis for the development of this central scenario (Example Reference Biosphere 2A). The BIOMASS methodology also provided a route map for the development of the biosphere assessment model, starting with the assessment context (Table 1).

Table 1. Assessment context for the Kravi Hora biosphere assessment.

Endpoint	Annual effective dose to the representative person (dose constraint 0.25 mSv/year) Specific/volume activity in environmental media
Philosophy	Equitable - transport parameters Cautious - representative person definition and parameters of exposure pathways
Repository type	Deep geological repository
Site context	Inland Aquifer at accessible depth No biosphere change
Geosphere/Biosphere interface	Well for domestic and agriculture use Concentrations of radionuclides in the groundwater are provided by the geological model
Time frame	0 -1, 250 years (step 1 year) 0 - 1 million years (step 100 years)
Societal assumptions	Agricultural community (modern practices) Capability to produce locally all needed foodstuffs (plant and animal products)

Discharge areas are all located around small rivers. However, groundwater extraction via a well that is used for drinking and agricultural water is considered as the source of contamination to the biosphere in the central case.

An interaction matrix, based on that in the BIOMASS methodology, has been developed and a database of input data/parameters compiled for the Kravi Hora site. Local data have been selected by preference, supported by regional and national data, as required. Where additional data were required, IAEA data compilations have been used, along with information in BIOPROTA documents. Some data sources are set down in national legislation, such as the use of ICRP dose coefficients.

The representative person is an adult that farms agricultural land irrigated with water from a contaminated well. The well is also used for drinking and domestic water use, and for drinking water for agricultural animals. The exposure pathways considered for the representative person are detailed in Table 2. The behaviour of the representative person has been based on habits data from the site, with cautious data being selected.

Table 2. Representative person exposure pathways.

Source	Exposure pathway
Water from a well that is used for domestic purposes	Ingestion External irradiation (bathing and showering)
Water from a well that is used for irrigation of agriculture soil	Inhalation (in the form of aerosol during irrigation)
Atmosphere (internal/external)	Inhalation (suspended soil - indoor and outdoor)
Agriculture soil	Ingestion (with foodstuffs and direct consumption) External irradiation
Plant products	Ingestion
Animal products	Ingestion

The conceptual model is illustrated in Figure 6. Irrigation is considered for all agricultural crops, but no interception is considered for cereals since these are not normally subject to irrigation in the Czech Republic. The mathematical model has been implemented in GoldSim, with equations largely drawn from the BIOMASS reference biosphere example that the scenario is based upon. However, modelling of C-14 has been based on the IAEA specific activity model for C-14, as detailed in IAEA TRS 472, with full specific activity equilibrium assumed throughout the terrestrial environment and food chain.

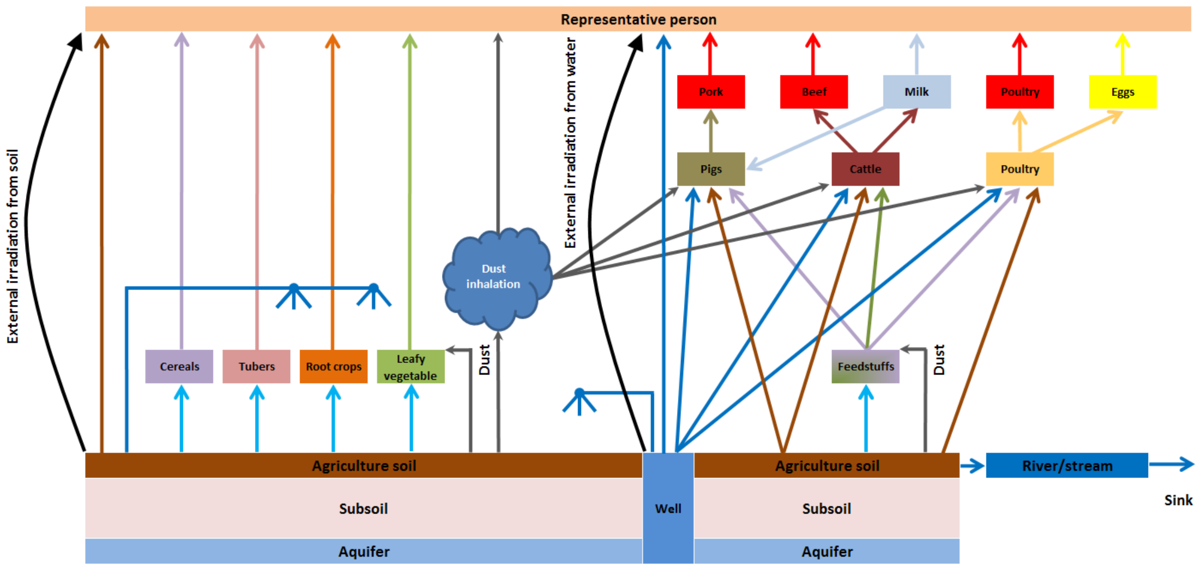

Figure 6. Conceptual model for the Kravi Hora biosphere assessment.

The model has been applied for the first iteration of the performance assessment and sensitivity analysis is planned for later in 2018.

Discussion

The focus of the biosphere model is on an agricultural system; other pathways, such as exposure of people from recreational habits such as swimming, have not been considered to date.

2.6 MULTI-SCALE SURFACE WATER – GROUNDWATER INTERACTION ON CATCHMENT SCALE

Anders Wörman presented on behalf of KTH Royal Institute of Technology and SSM.

There are different scales of water circulation in streams and rivers, ranging from regional groundwater circulation to hyporheic flow that occurs below streams. These different scales have implications for the transport of radionuclides. A project has been undertaken to look at hyporheic zone processes, funded by SSM and the EU Horizon 2020 framework programme, which supports a training network for enhancing the understanding of complex physical, chemical and biological process interactions.

The hyporheic zone is located below streams. Within this zone, groundwater and surface waters mix, with circulation patterns being affected by a number of factors, including stream bed topography and both the location and size of groundwater upwelling zones. Variation in pressure can result in small isolated circulation patterns (hyporheic flows) that can vary in size, with groundwater flow being compressed between these circulation patterns. There is, therefore, interaction between hyporheic and groundwater flows.

Stream bed topography has an important influence on hyporheic flows, along with surface roughness. The project aims to develop a greater understanding of the importance of these flows in terms of their influence on the patchiness of groundwater upwelling (both large and small scale groundwater flow) and exchange intensity through Quaternary deposits and residence time for solutes in Quaternary deposits.

A site-specific study has been undertaken on a small watershed in northern Sweden. Fourteen stream reaches were selected within the Krycklan catchment and a monitoring programme of surface-water and groundwater interactions implemented. The monitoring programme has included temperature and radon measurements. Modelling has also been undertaken.

Both large- and small-scale models can be superimposed to study the effect of the two flow fields (groundwater and hyporheic). Topography drives the circulation of groundwater and this has been modelled using COMSOL. Small-scale topography then drives the hyporheic flows, but modelling this is more challenging due to the need for fine detail topography data for the stream bed. Such data were derived by studying water fluctuations relative to variation in the stream bed. The water surface fluctuations were smaller than stream bed fluctuations as one controls the other and the ratio decreased with wave length. Generalisations then allowed data to be derived on the scale of centimetres.

The mean exchange velocity in stream beds was also modelled in terms of small hyporheic and larger scales and the fragmentation of upwelling zones considered. The stream bed has both upwelling and downward flow zones and these areas were defined for various stream orders (relating to the size of streams). The fragmentation was found to vary with stream order, the greatest fragmentation being observed for 1st order streams.

A hydrograph experiment has been undertaken. It was possible to dam the water and then release it. Both radon and temperature measurements were taken during this experiment. Radon content was significantly increased under drawdown. During flooding events the upwelling of groundwater reduces and radon is reduced. For temperature, clear differences were observed in relation to the depth to which diurnal stream temperature variation was measured under groundwater discharge and recharge conditions with the greatest variation over depth being measured during groundwater recharge.

Small-scale hyporheic flow was concluded to be, in general, much more intense than large-scale groundwater upwelling with the interaction of small and large scale flows fragmenting upwelling zones and focussing them on minor areas. The radon and temperature data indicate limited regions in streams where deep groundwater discharges. Further work is required to obtain more data on radon and temperature, which are important in understanding the effect of upwelling and hyporheic flow in stream bed sediments.

Discussion

Bedrock fractures were not accounted for in the studies undertaken and may have some impact where large fractures are present. Upwelling zones were normalised over a 5 m^2 distribution range.

2.7 CURRENT STATUS OF NUMO'S BIOSPHERE ASSESSMENT: DEVELOPMENT OF VARIOUS EXPOSURE PATHWAYS MODELS

Sanae Shibutani presented on behalf of NUMO.

No site has yet been selected in Japan for a geological disposal facility and there are not currently any candidate sites. A generic assessment approach is therefore being taken.

Various exposure pathways models are being developed that account for various life styles and work types to allow biosphere assessment that will support the site-investigation stage of the disposal programme. The use of various lifestyles and work types also aims to support public communication, ensuring that lifestyles represented in the models relate to public behaviours. Exposure models have therefore been revised to account for primary industry workers (agriculture and fisheries (river, marine)) and other exposure groups (e.g. other outdoor workers, indoor workers and city dwellers). The models have also been revised to enable child and infant exposures to be considered with a representative child of 10 years of age and a 1 year old infant being included by assuming food types consumed are largely the same as for an adult, but with quantities revised.

The exposure models have been used to derive DCF's. Comparison of the DCFs allows the various pathway models to be compared for the different radionuclides and GBI scenarios (e.g. well water extraction, marine or river discharge).

The previous version of the exposure model adopted an 'all or nothing' approach to consumption habits whereby farmers ate agricultural produce only (no fish) and fishermen did not eat contaminated crops. The revised model assumes that each exposure group inhabits the contaminated area and so drinks water and eats local produce, in addition to exposure group specific habits such as fishing. A market dilution approach was employed in trying way to confirm its effect.

The various exposure pathways modelled allow differences in exposure from different lifestyles to be considered.

2.8 MODELLING OF RADIONUCLIDE TRANSFER IN A SCOTS PINE FOREST ON TOP OF A SLUDGE HEAP AT A BELGIAN NORM SITE

Jordi Vives i Batlle presented on behalf of SCK·CEN.

A NORM site in Belgium, located in Ham, has been classed as a scientific observatory site within the EC TERRITORIES project. This is a forested site that contains a historical Belgian phosphate industry sludge heap. As a result of past activities, the site is contaminated with heavy metals such as arsenic, cadmium and lead, in addition to radionuclides (primarily Ra-226 and its progeny). The main risks at the site are associated with the chemical contaminants. The Ra-226 concentrations in the sludge are around 3-4 Bq/g. Contamination of the area is heterogenous, largely due to the presence of drainage canals. Trees growing at the site (pine and oak at around 20 years of age) are in poor health and are smaller than those growing in uncontaminated areas; the soils are of low nutrient status as well as being heterogeneously contaminated. Many of the trees present are crooked and branching patterns are considerably different from those of trees in uncontaminated areas. The trees at the observatory site are being compared with those in a forest plot at Mol, which has uncontaminated soils of good nutrient status and trees are healthy.

A monitoring station has been installed at the observatory site with the objective of deriving parameters and input data for a forest circulation model called ECOFOR. Various monitoring systems have been installed at the observatory site, including sap-flow sensors, light sensors, soil moisture probes, rain gauges and temperature sensors, that are integrated in an electronic data logger. Seasonal samples have also been taken from trees (roots, bark, wood, branches, tree needles, litter fall) and soil and analysed for radionuclide content.

The ECOFOR model considers interactions between soil, vegetation and atmosphere and follows the cycling of contaminants within trees. The model can consider underground, topsoil and/or atmospheric sources of contamination. Water/energy fluxes are the driving force behind the model. It is being calibrated and verified against field data (precipitation, transpiration, understorey evaporation and hydrology) derived from the observatory site.

A process-based interaction matrix has been developed, based around the water balance in soil and uptake by trees through evapotranspiration and subsequent release to atmosphere. The model itself has been implemented in the ModelMaker software. This software allows models to be developed without coding experience and includes necessary solvers.

There are three main model components:

- a simplified representation of hydrology (water from rainfall infiltrates soil with excess water going to groundwater recharge and hygroscopic, capillary and gravitational water are balanced);
- a plant transport sub-model (root uptake is balanced against evapotranspiration with upward flow through xylem and downward flow through phloem and with water interception, washout, litterfall and decomposition all being taken into account); and,
- linking of elements to water fluxes, taking account of retardation processes in soil and selectivity coefficients.

Of the three main components, hydrology is the most difficult, requiring a balance between complexity and parameter demand. The approach to addressing hydrology has been to consider fill capacity with limits of saturation in soil being set, along with a semi-‘tipping bucket’ approach, such that water flows from adjacent layers when soil moisture is between the limits. Within soils, there is an available and unavailable fraction according to sorption, with the available fraction being accessible for root absorption.

For root uptake, an exponential root model is used, which assumes roots are exponentially distributed with depth such that water can be extracted from different soil layers. The total root uptake rate is balanced against the total transporation demand. Once within plants, water is transported through the xylem to leaves according to the Poiseuille equation and downward phloem transport (leaves to roots) is described by a downward osmotic pressure gradient. Together, these allow cycling through the plant to be represented. The transport of water through plants is driven by evapotranspiration (the sum of transpiration and evaporation), which itself depends on solar flux and the leaf area index (which determines the amount of solar radiation on leaves versus soil) and is measured experimentally.

The atmosphere part of the model considers both dry and wet deposition. For wet deposition, soil saturation is taken into account in determining whether rivers/groundwater are recharged. A classic approach to interception by plants has been applied through the application of coefficients for interception, washout, absorption and leaching.

The transport of elements is then modelled according to the water flux with a retardation factor applied along with a selectivity coefficient for uptake into plants. For some elements the selectivity coefficients between different parts of trees (e.g. roots to wood and wood to leaves) are based on experimental data (presented in Gielen et al [2016][a]). This is a simple approach to representing element transfer, but comparison with a Cl-36 model has shown it to work well. Stable element analogues are being used, as appropriate, to derive coefficients for radionuclides.

The minimum data requirements for the model are as follows.

- Plant coefficients: interception, washout, absorption and runoff.
- Time-dependent data for evapotranspiration: temperature (min/max), humidity, LAI, crop coefficients, solar irradiation, precipitation.
- Selectivity coefficients for solutes in the tree.
- Atmospheric parameters: heat capacity of air, relative humidity, air density, atmospheric pressure, wind speed.
- Hydrology: field capacity, saturation hydraulic conductivity, porosity, residual water content.
- General physics data: surface tension and viscosity of water, gravity, ideal gas and Van'tHoff constants, acceleration of gravity.

All parameters and data for the model are being documented within the TERRITORIES project and sensitivity analyses are being undertaken to evaluate how sensitive the model is to different processes. The model has so far been set up for the Mol and NORM forest observatory sites, informed by data derived from the monitoring equipment installed at each. Samples of sludge from the NORM site are currently being analysed. These data will be used as input to the model, when available.

[a] Gielen, S., Vives i Batlle, J., vincke, C., Van Hees, M. and Vandenhove, H. (2016). Concentrations and distributions of Al, Ca, Cl, K, Mg and Mn in a Scots pine forest in Belgium. Ecological Modelling 324: 1–10.

Preliminary results from the ECOFOR model were presented. The model successfully predicts the daily potential evapotranspiration results for pine trees based on climatological data for the Mol site for the period 1984-1998 and has been shown to be consistent with predictions from a standalone Cl-36 model when assuming a constant Cl-36 solution concentration below a constant water table.

The water profile at each site has been modelled and clear differences are observed. The NORM site has a humus layer above the sludge whereas the Mol site has a freely draining sandy soil, which explains the differences observed. The model output, in terms of water profile, has been compared for the Mol site with measured data and the profiles provide good approximations. Transfer factors for a range of elements as a function of time have also been calculated and the results are in line with expectations (insoluble U-series radionuclides had low transfer factors, trace metals had intermediate values and nutrients and soluble radionuclides had the highest values). The response of the model to dry periods has also been investigated. As rain stops, wilting occurs in plants if roots are not within a soil layer containing water, as would be expected.

The model continues to be improved and, to date, all necessary processes have been implemented. Characterisation of the NORM site continues and data derived will be used to optimise the model, which will then be compared against other simpler models. It is also intended that the model will be applied to various other sites for further testing.

Discussion

Results indicate that Kd is an important parameter affecting cycling of elements by determining what is bioavailable. However, plants themselves will have a large influence on the system to ensure that they derive what they need from soils. The selectivity coefficients used in the model were measured experimentally and therefore help address the issue of plants influencing the behaviour of elements in soils.

2.9 MULTI-SCALE EXPERIMENTS AND MODELS FOR RADIONUCLIDE WASTE DISPOSAL: UPTAKE AND DOSIMETRY IN A NATIVE GRASS

Dawn Montgomery presented on behalf of Clemson University.

A large collaborative project is underway in the USA between the University of South Carolina, Clemson University and South Carolina State University on radioactive waste disposal and the development of multi-scale experimental and modelling capabilities. The overall goal is to unravel the complexity of chemical, biological and microbial interactions that affect radionuclide mobility in natural and engineered systems, and how these interactions can be incorporated into assessment models. The focus is on the main risk-driving radionuclides for radioactive waste disposal facilities, such as isotopes of neptunium, technetium, caesium, uranium and iodine. The overall project involves around 50 students across a multitude of faculties, and has four distinct tasks:

- development of robust, high capacity waste forms;
- understanding the influence of coupled chemical, physical and biological processes on radionuclide transport in the environment;
- upscaling from laboratory to field-scale ecosystems (field lysimeter experiments), pore scale imaging and integrated monitoring systems; and
- reactive transport models predicting radionuclide release from an engineered system and transport through the environment.

Research is being undertaken to look at ion interactions, biogenic ligands (microbial and plant), and redox processes and how these interact to affect radionuclide transport across different spatial scales. The aim is to investigate the time and length scales over which non-equilibrium states are maintained by rate limiting (or enhancing) reactions.

The particular aspect of the project presented was research that has been undertaken on radionuclide uptake and dosimetry in plants. Work initially focussed on the effect of plant ligands on soil sorption and has now moved to hydroponic studies to look at plant uptake and dosimetry before considering combined soil sorption and uptake through plant-soil column studies. The motivation has been to obtain insight into the mechanisms leading to the upward mobility of radionuclides that cannot be explained by diffusion alone.

The propensity of the grass *Andropogon virginicus* to take up radionuclides has been evaluated, with a particular focus on the effect of plant root exudates on the mobilisation of radionuclides and their subsequent uptake. For example, where soil phosphate is less available, plants are required to forage more to meet their phosphate needs and this, in turn, can result in greater uranium uptake. Controlled hydroponic experiments have been undertaken to investigate. Metal ions are transferred through the xylem of plants as free ions or as conjugates that move with water. Once in the shoot, metal ions are subcellularly partitioned or detoxified, with a small portion being cycled back to root tissue via the phloem.

Plants of an appropriate size were subject to 1 week's acclimatisation in the laboratory in a hydroponic nutrient solution. After acclimatisation, the hydroponic solution was spiked with 75 parts per billion (ppb) Tc-99 or 10 ppb Np-237, U-238 or Cs-133. There were three spiked groups and one control. Plants were harvested at 1, 3 or 5 days and roots rinsed and shoots separated. One plant per group was selected for autoradiography. The remaining plants were dried and digested prior to analysis via inductively coupled plasma mass spectrometry (ICP-MS) and liquid scintillation counting. The hydroponic solution was also analysed. Experiments were run for both seedlings and established plants.

The autoradiography of plants spiked with Tc-99 indicated a positive correlation of uptake of radionuclides with time, with established plants showing a greater root to shoot transfer. For seedlings, the 5 day exposure resulted in a higher uptake. The harvest day was also found to be significant for seedlings spiked with Cs-133. Both Tc and Cs have nutrient analogues and incorporation within plants was therefore expected. Variation was observed between uptake to root and shoot in established plants.

In the case of Np-237 for which there is no nutrient analogue, incorporation was not expected. Results, however, indicate uptake to both root and shoot of seedlings and established plants with plant part, harvest day and plant age all being significant in determining the amount of uptake. For U-238, which also has no nutrient analogue, root uptake was significant in both seedlings and established plants with much lower uptake being observed in shoots. The high root uptake is likely due to the plant being grown in a hydroponic solution; a much lower uptake would be expected in soil where sorption would be possible. For established plants the harvest day was significant, but the influence of plant age was not significant.

Key findings from the hydroponic experiments were that many radionuclides are incorporated into plants, with the concentration ratio varying according to the radionuclide, time of exposure (plant age and harvest day) and the plant part. Roots tended to have higher concentration ratios, but this could result from lack of sorption of the radionuclide to soils.

The most recent experiments undertaken have been on seedlings transplanted into 25 cm columns filled with soil and sand (the latter being to avoid column compaction). Plants were allowed to acclimatise, during which time they were irrigated and effluent collected. Radionuclides were then injected at a depth of 7.6 cm with either 1mg/L Tc-99 or 0.1 mg/l Cs-133, Np-237 or U. The injection site was chosen to ensure interaction between the radionuclides and the seedling roots. Shoots were then harvested after 4 weeks and columns covered and held at a constant low temperature until separation of roots from soil. The different plant parts and soils will be dried prior to analysis.

The dosimetry part of the project has also progressed, with the ultimate goal of combining refined dosimetric models with models describing temporal uptake in *A. virginicus* to allow temporal dose rates to be calculated. Current dose assessment approaches for biota (e.g. ERICA and ICRP Reference Animals and Plants) assume uniform radionuclide distribution throughout an ellipsoidal representation of the body of an organism, although it is possible to consider spherical organ doses if necessary. In terms of grass, the ICRP approach is to represent the plant as a single ellipsoid representing a spike of grass. Voxel phantoms are an alternative approach to biota dosimetry that encompass more biological relevance by allowing different organs and tissues to be specifically represented.

A stylised phantom model for roots and shoots of the experimental grass within a flask has been developed. This stylised phantom model considers three cylindrical roots of 10 cm by 0.5 cm immersed in water in a glass flask and three elliptical cylinder shoots of dimensions 18 cm by 0.2 cm by 0.05 cm. The grass itself has also been subject to computed tomography (CT) scanning, allowing a 3D voxel phantom to be created within the 3D Doctor & Lattice Tool. A comparison of the whole plant dose conversion factors (DCF) compared to those of the ICRP Reference grass indicated differences, particularly for external DCFs, ranging between one and three orders of magnitude, with the external DCFs for the ICRP Reference Grass being higher in most instances. A less pronounced difference is evident for internal DCFs (all being within a factor of 0.3).

Voxel phantom models take longer to develop than stylised phantom models, but the former are more realistic than traditional ellipsoid models. Nonetheless there are limitations in their use and a balance is therefore needed between realism and practicality when undertaking biota dose assessments. For example, whilst calculated dose rates for biota are low in relation to most anthropogenic activities, there are instances where screening values have been exceeded. Where appropriate voxel models are available, their application could be useful in undertaking more detailed dose assessments in such situations.

Discussion

In addition to active uptake processes, diffusion (i.e. passive uptake) could be an important means by which radionuclides enter plants. For soil columns, the distribution of water will vary and this may affect sorption of redox-sensitive radionuclides and, hence, should be measured. Kinetics of sorption has been studied in field lysimeter experiments undertaken by Imperial College London and the output of these studies may provide useful input to the ongoing experiments.

2.10 AN INTEGRATED ANALYSIS FROM REPOSITORY THROUGH ROCK TO THE SURFACE: PRELIMINARY SFL RESULTS

Olle Hjerne presented on behalf of SKB.

The SFL repository in Sweden will be for long-lived LLW and ILW (see also the presentation by Ulrik Kautsky, section 2.3 above). The design and location of the facility have not yet been decided, but it is likely to be located at a depth of around 500m. The facility will have two waste vaults. One will be for the disposal of metallic waste from nuclear power plants (>98% of activity) and the other for legacy waste from nuclear research programmes, hospitals and other industries (<2% of activity). Metallic waste will be surrounded by concrete. Legacy waste will be surrounded by bentonite. A preliminary safety evaluation has been made to evaluate whether the disposal concept has the potential to function and to inform on the site-selection process.

Data from site characterisation work at Laxemar have been used in the safety evaluation. One biosphere object (a cultivated field) from the Laxemar site was selected with the assumption that the repository discharge is to this object, which is either a permanent agricultural field or a mire that can be used in various ways. Alternative biosphere objects were also selected to investigate what would happen if discharges occurred elsewhere. Various calculation cases have been undertaken, but the focus of the presentation was on the base case.

Radionuclide transport is often considered in terms of separate models for the near field, transport through the bedrock, transport through the biosphere and dose calculations. The approach at SKB for the SFL repository, however, is to develop an integrated model from the waste all the way through to dose calculations, thus allowing the whole system to be evaluated in one go. This requires some parts of the transport process to be simplified, but checks are undertaken against other models to ensure the integrated model provides consistent output.

Preliminary results were presented to illustrate dose patterns over time (up to 1 million years) using the integrated model. Higher doses were calculated when the biosphere object receiving releases is assumed to be a mire that has been drained and converted for agricultural use rather than a field that has always been used for agriculture; this is mostly due to the initial accumulation of radionuclides in the mire system prior to drainage. The waste vault for metallic wastes results in higher doses compared with the vault for legacy waste.

Different land-use variants for a mire release have been investigated, including hunting and gathering, infield-outland farming, draining and cultivating, garden plot and use of a dug well for drinking and irrigation water. The highest doses were associated with the draining of a mire for cultivation with or without a dug well. The dose contribution by radionuclide has also been considered. At 10,000 years, Mo-93 is the greatest contributor to dose. Cl-36 is also important and, in longer timeframes, Tc-99 dominates dose, although the quantity of Tc-99 present in waste is uncertain and it may not be present at all.

With Mo-93 dominating exposures in the first 10,000 years, the fate of this radionuclide throughout the whole disposal system and key exposure pathways have been investigated. The proportion of Mo-93 in waste decreases over time as it migrates through bentonite or decays within the waste (half life of 4000 years). Of the Mo-93 reaching the geosphere, much will be sorbed and subject to further decay. As a result, less than 1% of the Mo-93 in the waste is transported to the biosphere. For Mo-93 in the biosphere, the dominant exposure pathway relates to uptake by cereals and their subsequent consumption. The consumption of potatoes is also a contributor with drinking water contributing only a small fraction to the overall exposure.

The fate of other radionuclides with different behaviours and half-lives has also been investigated. The half-lives of radionuclides in the U-238 decay chain decreases through the chain. Differences in behaviour are notable. For example, uranium sorbs to the upper layers of soil that can be cultivated whereas thorium and daughters sorb strongly to glacial clay and till. If a unit release rate is considered for each radionuclide in the decay chain, ignoring radionuclide decay and daughter ingrowth, uranium accumulates in the upper regolith layers while others such as thorium and daughters are retained in till.

In terms of dose over time, U-238 is the greatest contributor for most of the time, with the curve for dose contribution over time matching that for the bedrock release. Ra-226 has two dose contribution peaks, one early on and a second much later. The first matches the Ra-226 bedrock release, whereas the second peak is more pronounced than the bedrock release due to ingrowth from parent radionuclides. The dose contribution and bedrock release curves are illustrated in Figure 7. In terms of exposure pathways, food intake is dominant for U-238 which reaches the cultivated soil following bedrock release whereas for Th-230 and daughters, which do not reach cultivated soil following a bedrock release, dose is primarily from consumption of drinking water from a well. However, for Ra-226, ingrowth from U-238 reaching the cultivated soil enables food consumption pathways to increase in terms of dose contribution at later times.

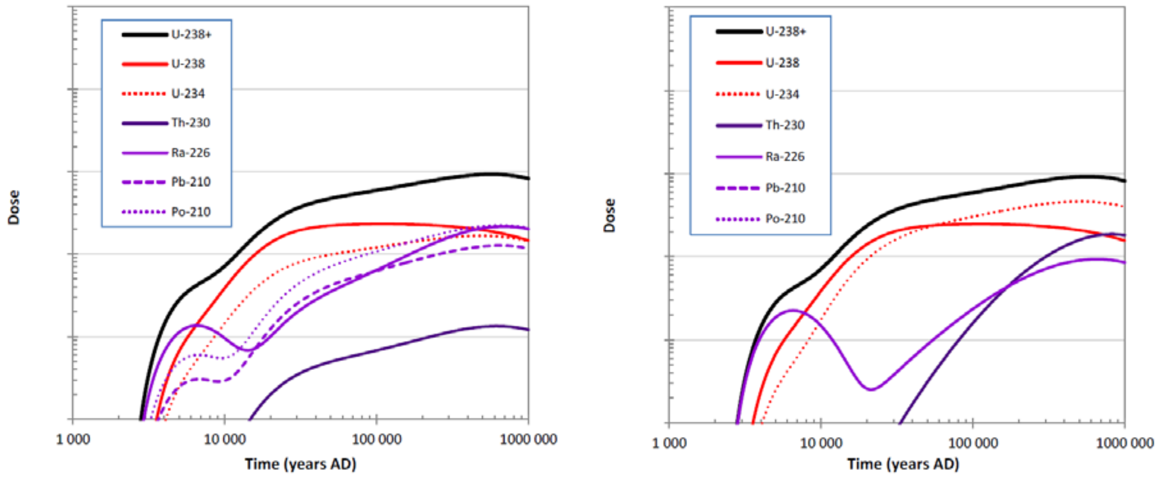

Figure 7. Dose contribution by U-238 series radionuclides (left) and from bedrock release (right).

Understanding how radionuclides behave in the geosphere and biosphere and their form within the waste is important. For example, if a higher Kd is assumed for uranium in bedrock, doses are initially lower as a result of reduced transport of uranium to the surface. However, doses at later times (around 1 million years) are increased as uranium is retained in rock where it decays to daughter products that are then the contributors to dose at later times with drinking water being the key exposure pathway. The retention of uranium in bedrock can result in disequilibrium in the decay chain that can have an important effect on the dominance of exposure pathways. Such understanding can help inform the development of the repository concept.

Discussion

Doses from the U-238 decay chain do not yet account for the contribution from radon. Discussion is ongoing within SKB as to how to incorporate radon doses within the model. It was noted that a U-238 series modelling paper by Danyl Perez-Sanchez and Mike Thorne includes advective transport of radon in soils and could give an idea on the transport of radon relative to radium.

2.11 IMPORTANCE OF STAKEHOLDERS INVOLVEMENT IN REGULATORY DECISION MAKING – NORWEGIAN EXPERIENCE

Jelena Popic presented on behalf of NRPA.

The presentation was focussed on lessons learned as a regulator on the involvement of stakeholders within the process of regulatory decision making. Biosphere assessments support decision making;

where results indicate acceptable risks, then decisions can be made. However, in some cases, stakeholders may have not been included in the decision making process and may have views that are not aligned to risk assessments. Where such views are not addressed, experience shows that problems may be faced.

According to the OECD/NEA, a stakeholder is any actor (institution, group or individual) with an interest or role to play in the process of making decisions. The European Commission has also addressed the topic of stakeholder involvement with Council Directive 2011/70/EURATOM of 19 July 2011, which states that "*transparency should be provided by ensuring effective public information and opportunities for all stakeholders concerned, including local authorities and the public, to participate in the decision-making processes in accordance with national and international obligations*". This was similarly followed in 2015 by the IAEA calling for the involvement of stakeholders in the process of decision making around important issues relating to nuclear power, radioactive waste management and radiation protection, in order to enhance public awareness, understanding and confidence. In the last two decades there has been a shift from anthropocentric to ecocentric attitudes toward radiation protection, which has driven greater interest from stakeholders in participating in decision making regarding health and safety issues as well as environmental protection issues.

There can be different levels of stakeholder involvement ranging from a high level of involvement and influence, where stakeholders are fully involved in the process of finding and implementing solutions, to a low level of involvement and influence, where stakeholders are informed, but not necessarily engaged. Too often it is this lower level of engagement that is applied, which can result in issues.

The Norwegian Radiation Protection Authority (NRPA) is the national competent authority regarding radiation protection and nuclear safety in Norway. The main activities of the NRPA are the regulation and inspection of radioactive sources, monitoring doses to the public, workers and patients and to the environment, leading the Norwegian Nuclear and Radiological Emergency Organisation, maintaining an overview of current knowledge regarding risks and effects of radiation and participating in international projects, including long-term bilateral regulatory cooperation. The relevant stakeholders in Norway include the various policy and legislation actors, regulatory authorities (NRPA, the Norwegian Environment Agency and other directorates and ministries), implementing organisations (e.g. companies with licences for working with radioactive materials), scientific research institutes, non-governmental organisations (national and international), industry (e.g. oil and gas and process industries), and regional and local level communities (including state and expert groups and local organisations).

Three case studies were presented to highlight experience and lessons learned around stakeholder involvement in the process of regulatory decision making. The case studies relate to the management of legacy sites and radioactive waste and pollution associated with NORM rock waste in Norway.

The Søve legacy site is a former niobium mining site located in a NORM-rich Fen Complex area. The mine was active between 1953-1965 and has been decommissioned, but a lot of radioactive waste was left on the site in the form of rocks, slag and soil, resulting in high gamma dose rates (up to 20 µGy/h). Waste associated with the former mining site includes around 825 tonnes of slag with enhanced levels of Th-232 and U-238, along with areas of polluted soil, slag and sludge with activity concentrations of NORM that exceed national exemption levels. Outdoor Rn-222 activity concentrations of up to 1200 Bq/m^3 are associated with the site. The mine was state owned, but the exact responsibility for cleaning up the site has been open for some decades until, in 2011, the Ministry of Trade and Industry took responsibility.

The NRPA required the Ministry to characterise the site and develop a final plan for clean-up with proper measures for handling and disposing of radioactive waste. These activities were appropriately performed between 2012 and 2016 with the Borge disposal site being selected for the final waste disposal, which was approved by NRPA. However, the solution was decided upon without giving special attention to stakeholder views. A political case in the local community resulted in media coverage and pressure from local people to stop the disposal process at Borge and activities to clean up the site were halted. Discussions are now ongoing at an alternative disposal site, but with greater stakeholder involvement as a result of lessons learned. In addition to the need for overall stakeholder involvement in the decision making process, the Søve legacy site case identified the need for better risk communication. As such, several discussion panels have taken place involving local people, experts, journalists and politicians in moving toward a new solution for the management of the Søve legacy site. However, it is not easy to change peoples' perceptions and opinions.

The second case study focussed on radioactive waste management at the Borge disposal site itself. The Borge disposal site applied for a licence for the disposal of Alum Shales and acid-forming rocks, which was needed in Norway. The licensing process was all completed properly with NRPA and the local community jointly organising several panel discussions where stakeholders could discuss the issues. The good communication and consultation throughout the process contributed to public reassurance with regard to radiation risks, and the license for operation was granted. Two years after the license was granted and operations at the site had begun, an application was submitted to NRPA for the disposal of 14,000 tonnes of low activity NORM waste from the Søve legacy site. There was no regulatory reason why the disposals could not progress, but significant public attention and local resistance resulted in the disposal being stopped. Negative public attention prevented the right disposal solution from being implemented. The negative attention around the Søve legacy site as a result of poor stakeholder involvement impacted on the Borge disposal site, which previously had a good result with regard to disposal of low radioactivity material following a good, intensive stakeholder involvement process.

The third example focussed on a TiZir Titanium and Iron (TTI) – ilmenite facility producing titanium slag and high purity pig iron (HPPI), the only such facility in Europe and only one of five in the world. The facility has a license for NORM discharge to water and air, issued by the NRPA. The facility is located near a fjord and there was concern from local people about pollution of nature. Both before and after the licensing process, there was a lot of stakeholder engagement. NRPA organised several meetings with industry to disseminate relevant knowledge and promoted open discussion around possible risks and the licensing process. Stakeholder needs and concerns were anticipated and site characterisation and safety reports, supported by modelling, concluded there was no risk for nature or for people present in the area. Good communication around risks resulted in local stakeholders and non-government organisations being reassured and the licensing process proceeded. This case illustrates how consideration of stakeholder needs and concerns at an early stage can lead to good results in regulatory decision making.

As the cases illustrate, whilst the question of stakeholder involvement might appear trivial it can, in practice, cause problems such as serious delays and can have significant financial implications. The communication of risk can be difficult, but early engagement and transparency can help in achieving positive outcomes.

To help in communication around risks and regulatory decision making, it may be worth considering engaging with social scientists to evaluate the weakest points and provide guidance on how to ensure the best communication to the benefit of all.

Discussion

Radiological risks are often lower than chemotoxic risks for NORM industry wastes and all risks should be treated proportionately. A holistic legislative approach is taken in Norway with all pollutants being considered. Consultation panels organised as part of stakeholder engagement programmes aim to answer questions around all risks and not just those associated with radioactivity. Nonetheless, experience shows that people tend to be more concerned about radiation than other hazardous materials, such as heavy metals etc. The consultation panels aim to provide reassurance and explanation of the risks. This can, however, be a real challenge, particularly in countries where there are different regulators and regulatory regimes for chemicals and radioactivity.

2.12 UPDATE ON SCREENING AND MODELLING OF NON-RADIOLOGICAL POLLUTANTS IN A GENERIC DISPOSAL FACILITY

Ray Kowe presented on behalf of RWM.

The goal of the Groundwater Daughter Directive (GWD) is to protect groundwater resources and human health and it applies to radiological and non-radiological pollutants. 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 2010 (EPR10) (now consolidated into EPR 2016).

The Environmental Agency issued a Regulatory Observation (RO) to RWM relating to protection against non-radiological pollutants. The RO specifies a number of actions for RWM to address the requirement that the generic disposal facility (GDF) provides adequate protection against non-radiological pollutants which included 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 concentration of non-radiological pollutants at defined points along the groundwater pathway in a range of geological environments. Example pollutants have been selected for study by a screening process which consisted of:

- screening of hazardous substances drawing on 2016 assessments and recent JAGDAG (Joint Agencies Groundwater Directive Advisory Group) determinations: 45 potentially present in the GDF;
- screening of non-hazardous pollutants based on recent JAGDAG list: 57 potentially present in GDF;
- further screening: grouping, and ranking within the group according to attributes;
- resulting in 14 pollutants being selected for further study.

The TSM is under development. Two illustrative geologies taken from the 2016 RWM post-closure safety assessment will be modelled (higher strength and lower strength sedimentary rocks). The 2013 inventory for geological disposal will be used to derive the mass inputs for non-radiological pollutants. Concentrations will be output at various points along the groundwater pathway, especially at interfaces. Draft results are expected by the end of June 2018 and a draft project report in September 2018.

RWM met with the Environmental Agency in February 2018 to discuss the RWM project and plan to meet again once the project has completed.

Discussion

Previous assessments on chemotoxic substances have considered risk to humans, but current regulations require groundwater concentrations at various points to be considered rather than humans as receptors and consultation is currently ongoing as to the compliance indicators that should be applied.

Organic materials can be of concern. Organics may not persist in some geospheres and degradation will be considered in terms of effective chemical half-lives. It is considered unlikely that organic substances will move through the geosphere past the first few observation points, but this has not yet been modelled so no definitive answers can be given at this time. Qualitative screening has been undertaken by scoring groups of chemicals and their relative persistence to identify those that will be taken forward. Such screening helps to minimise data requirements. Experience has shown that in various assessment contexts it tends to be similar chemicals that are selected for further study.

2.13 INTEGRATED RADIOLOGICAL AND NON-RADIOLOGICAL ASSESSMENT FOR THE LLWR GROUNDWATER PATHWAY: THE HYDROGEOLOGICAL RISK ASSESSMENT AND OTHER REGULATORY REQUIREMENTS

Alex Proverbio presented on behalf of LLWR.

The UK Low Level Waste Repository (LLWR) is located on the coast in West Cumbria. The site is close to a designated site of special scientific interest (SSSI).

Disposals at the LLWR began in 1959 with the first disposals being tumble tipped into trenches. In 1988, a new disposal concept was introduced with subsequent disposals planned to be into a series of concrete vaults with wastes being grouted in ISO containers.

In 2011 an Environmental Safety Case (ESC) was submitted to the Environment Agency, which was reviewed and found adequate in 2013, leading to a revised environmental permit application being submitted. This revised permit was granted in 2015, allowing for disposals of LLW in up to Vault 20. Radiological capacities were also stated in the permit. In 2016, planning permission was granted, allowing disposals to continue up to Vault 11. An updated ESC is due to be submitted in 2021.

The 2011 ESC responded to 5 principles and 14 requirements set out in Guidance on Requirements for Authorisation (GRA) for near-surface disposal facilities on land for solid radioactive wastes. The ESC was required to provide a coherent case for the entire site, based on a solid understanding of site geology, hydrogeology, coastal erosion, chemical evolution etc. A proportionate assessment was required for the period of authorisation and after, which was to cover several exposure pathways (i.e. groundwater, gas, human intrusion, coastal erosion) for radionuclides and non-radioactive contaminants. Optimisation was another key requirement in the GRA, and impacted on several aspects of the site, including the engineering design.

The ESC is also used as a tool for supporting development and management of the LLWR. The Permit's Improvement Conditions have been included in the schedule of work required for the submission of the updated 2021 ESC. One of the improvement conditions required a non-radiological hydrogeological risk assessment (HRA) to be submitted in 2017, taking into account the Environment Agency's review of the 2011 ESC. The work underpinning the HRA included a general update of the groundwater pathway models. Further regulatory interactions defined the details of the scope of the HRA.

In the UK, the control of non-radioactive contaminants for a near-surface radioactive disposal facility should be no less stringent that would apply at a landfill. One of the main issues in undertaking the non-radiological HRA was deciding on where to place compliance points. For radioactive assessments, there has been considerable work through the years on defining potential exposure groups, but the placement of compliance positions for non-radioactive contaminants maintains a degree of subjectivity. For hazardous substances, the approach taken was that compliance points were defined for each vault and trench (after immediate dilution) and the maximum concentration was to be compared against the appropriate minimum reporting value. For non-hazardous pollutants, compliance points were selected at the site boundaries and the concentrations calculated were compared against the appropriate minimum reporting value.

Two inter-connected compartment models were used to describe different aspects of the system. A compartment flow model that calculates water flows and levels in the near-field was linked to an assessment model that models radionuclide / contaminant migration and calculates potential impacts. Other underpinning models were used to derive input information. Radiological and non-radiological assessments can now be performed with the same model.

The model represents the near-field considering the following processes: variation of saturation levels, unsaturated contaminant release, corrosion, sorption to soil and grout and solubility limitation were all considered. Within the geosphere below the facility, evolution of saturation levels, horizontal and vertical flows, sorption to geology were considered with retardation being simulated through multiple compartments. Receptors were then the hazardous and non-hazardous compliance points for non-radioactive substances. For radionuclides, five radiological pathways were considered (well, marine, estuary, stream and terrestrial discharge pathways). To understand uncertainties and sensitivities, a number of deterministic cases were run with single parameters being varied to consider how the system responds to each. A total of 13 deterministic calculation cases were presented in the HRA.

Of the radiological pathways evaluated, the well pathway was giving the higher risk. This considered human activities associated with a well in the region between the LLWR and the coast. The well was assumed to provide water for domestic use, garden irrigation and for hens and goats kept for egg and milk production, respectively. Risk was calculated considering the probability that the well could be sunk in different parts of the plume.

During the period of authorisation, some exceedances relative to non-radioactive hazardous contaminants were calculated at the compliance points, but these related to past peaks (in the period 1977 to 2003). Exceedance also occurred for the radiological assessment based around the well pathway, but these were again in the past and related to tritium. The radiological risk varies over time as a consequence of landscape evolution, which also impacts on the possible human activities in the area (reduction of area available for sinking a well). To allow risks associated with daughter ingrowth from U-238/Ra-226 chain, a very long term assessment was undertaken, with some exceedances occurring in the very long-term. However, such a scenario is very unlikely since sea level rise will disrupt the site before they could occur.

The HRA model is very complex, containing more than 3,500 elements and some verification of calculations was required. This was achieved using a scoping model (developed in Excel) that was developed specifically for the purpose. The near-field and underlying geosphere were assumed to be fully saturated with constant water flows in this scoping model. Solubility limitation was neglected. Results from the HRA model were compared with this scoping model to ensure that results were reasonable.

The Environment Agency was satisfied with the HRA submitted by LLWR. The model was developed to include significant technical enhancements from that applied for the 2011 ESC, including:

- integrated assessment of the period of authorisation and post-closure;
- improved assessment of impacts during the period of authorisation; and,
- inclusion of updated hydrogeological understanding.

The model has been used to calculate new site capacities for non-radioactive substances.

Several questions arise from the work undertaken to date.

- What is the appropriate level of complexity needed for assessment models and should stakeholders play a role in defining the level of complexity required?
- What is the geosphere-biosphere interface at LLWR?
- Should assessment models be used for management decisions? If a site is demonstrated to be safer than was previously thought, how can this be communicated? For example, in the past it may not have been possible to consign certain wastes, but, with scientific understanding having evolved it may now be possible. Such issues are difficult to communicate to stakeholders.

Discussion

The period of authorisation relates back to when the site first began operations. Therefore, whilst exceedances were noted during the period of authorisation, these relate to past peaks in contaminant concentrations and they have since reduced.

Complexing agents, of which EDTA is a representative molecule, may have an important effect on the migration of contaminants. By moderating retardation, the release over time will be influenced.

2.14 MODELLING HYDROLOGY AND TRANSPORT – PROGRESS AND PERSPECTIVES FROM SE-SFL

Peter Saetre presented on behalf of SKB.

As noted previously (see Sections 2.3 and 2.10), SKB are undertaking a preliminary safety evaluation for an SFL repository for long-lived LLW and ILW. No site has been selected and the safety evaluation is therefore intended as a 'laboratory bench' to inform on model developments in light of questions and comments from regulators and reviewers. Whilst the evaluation is site-generic, it is being informed by data from the Laxemar site that has been well described and characterised in the past. There are site data for hydrology and land uplift etc., along with 3D maps of soils. The use of real data from a site helps to identify assessment issues that might not be identified when using a range of generic data that are in no way correlated.

Site description provides a detailed account of a site as it is today (i.e. a snapshot in time), but does not give information on what a site will be like in the future. Information from the site description is needed to inform on model development, but the models need to be simplified representations of the system. There has been a lot of work undertaken recently at SKB in relation to model development.

Hydrology drives transport through soil layers and site descriptions have resulted in good resolution in the 3D site model for hydrological transport on a horizontal level, but it was not so good with respect to the vertical transport; more detail was needed. A conceptual water balance model for terrestrial ecosystems was therefore considered and a simple representation of soil hydrology developed by considering soil layers and the fluxes between them. This allows the implications of changes in soil layer parameters or water quantities to be considered. Hydrological fluxes are a function of net precipitation, surface runoff and soil depth. Flux into a soil layer may be vertical from within the catchment or through upward and downward flow through the soil layers, driven by the difference between precipitation and evapotranspiration.

In addition to soil layers, the model represents a drainage ditch as would be appropriate for an agricultural soil scenario. The drainage ditch allows excess water to be drained from the system, but deficits in water can also occur. There were insufficient site data for all land use scenarios of interest. For example, there were no data for wetlands as these do not currently exist at the Laxemar site. Alternative model concepts were therefore needed to ensure water balance was maintained under different hydrological fluxes and some statistical descriptions of fluxes had to be derived. Water balance data from MIKE-SHE were extracted and balanced across the Laxemar catchment. For percolation it was necessary to derive equations for different ecosystems. Percolation decreases exponentially with depth and depends on the thickness of the least conductive layer.

The effect of climate on groundwater flux has been investigated. Regional climate data (temperature, precipitation etc.) were gathered at different positions along the coast and used to consider the implications for groundwater fluxes. The changes in runoff and discharge can be described as linear functions and this was used to inform on water balance curves for different climates. As would be expected, greater runoff occurs under wetter climate conditions. The model has been used to inform how the water balance in a catchment is distributed over depth and has been a useful tool for setting bounds on the fluxes that could be reasonable under different climate conditions.

A sensitivity analysis has been undertaken to identify the important parameters governing radionuclide concentrations in pore water as a function of depth. The analysis for Cl-36 showed that, in lower soil layers, the Cl-36 concentration is governed by the flux of water from below and the area of the object. Upper soil layers were more strongly influenced by net precipitation. The key parameters influencing radionuclide concentrations in different soil layers vary according to the radionuclide of interest. For example, degassing is an important process for C-14 in upper soil layers.

The landscape development model has been simplified to allow its use in sensitivity analyses. The model is a simplified description of in-growth of lakes by vegetation and represents the time from lake isolation from the sea *due to post-glacial land uplift) until full terrestrialisation. However, the main landscape object in the assessment is terrestrial at all times and this simplified model has not, therefore, been developed further.

Key questions for safety assessments are where radionuclides enter the surface environment, how do they then disperse and dilute and whether the distribution of radionuclides in the surface environment is homogeneous. A 3D model is needed to inform on this. Such models can then be used to derive parameters as input to assessment models, but the extraction of appropriate data and parameters must be based on informed decisions considering the range of future conditions that may be applicable to a site. A ‘proof of concept’ project has been ongoing for some time on modelling of radionuclide transport and retention in the regolith. Possible surface release areas for radionuclides transported in groundwater were identified and one object selected as an area of interest for more detailed consideration in terms of hydrological modelling. Groundwater velocity vectors have been derived across a transect north to south of the object. The study has been informative and intuitive, highlighting issues around extracting information from complex 3D models to inform simpler models.

The accumulation of radionuclides within soil layers has also been considered. Accumulation of radionuclides occurs at certain points along a vertical soil profile depending on the radionuclide. For example, nickel sorbs to the till layer whereas molybdenum accumulates in two layers (glacial clay and organic layers such that two peaks are observed at different depths in the vertical profile).

Discussion

Results of the hydrological and transport modelling studies are due to be published toward the end of the year.

3. ENVIRONMENTAL MONITORING PROGRAMMES AND PRESERVATION OF BASELINE SAMPLES FOR THE FUTURE

NWMO is in the process of developing site characterisation programmes for candidate sites in Canada, with boreholes being drilled at one possible disposal site location. Learning what others with more advanced programmes have done in terms of sampling in environmental monitoring programmes, preservation of samples and associated costs could be useful in the development of the site characterisation programmes. A session was therefore organised on this topic. Presentations and associated discussions from this session are summarised below.

3.1 ENVIRONMENTAL MONITORING – A REGULATORY PERSPECTIVE

Jelena Popic presented on behalf of NRPA.

As noted in Section 2.11, the NRPA is the national regulatory authority regarding radiation protection and nuclear safety in Norway.

In 2011, the amended Pollution Control Act came into force in Norway, which requires radioactive waste to be regulated alongside other types of hazardous waste and for a holistic ecosystem approach to be taken to the protection of human health and the environment from multiple hazards.

Monitoring is required in relation to all planned exposure situations (where radionuclides are stored or handled) with monitoring being part of the authorisation and licensing process. Monitoring is also required in relation to existing exposure situations, including NORM legacy sites, but also radon-prone areas and NORM-rich areas that are not under regulatory control. There will also be monitoring required as part of emergency preparedness to ensure protocols for environmental monitoring in post-emergency situations are in place.

There are no nuclear power plants in Norway, but there are research reactors. There are also more than 170 licenses for waste management and pollution in Norway of which around 110 relate to NORM activities (particularly the oil and gas industry). There are six operational waste repositories. One is for radioactive waste from the nuclear industry, research, medical and other industries. Five are for NORM and hazardous waste or rock with the potential for acid leaching. The majority of wastes containing radioactivity relate to the oil and gas industry and construction projects.

Taking the above into consideration, there can be many different objectives to environmental monitoring programmes, including:

- complying with regulatory and international obligations;
- assessing impacts on humans and biota and the environment as a whole (i.e. inclusive of resources);
- assessing doses following operator changes/measures;
- detecting unregulated releases;
- providing reassurance to members of the public and other stakeholders;
- following trends in radioactivity in the environment over time; and
- investigating the behaviour of radionuclides (more a research than regulatory aspect).

Requirements for monitoring may be placed on operators to demonstrate compliance with authorisations under the Pollution Control Act and associated regulations. Regulatory bodies, including the NRPA, also undertake monitoring in support of regulatory roles and national and international obligations. In addition to checking monitoring results from operators to check authorisation compliance, NRPA undertakes its own monitoring programmes. Such monitoring includes radon monitoring and trends in radioactivity concentrations in plants and animals, and radiation doses to people following the Chernobyl accident.

Currently there are no guidance documents from the NRPA concerning monitoring of radionuclides and radiation doses, but there are plans for such documents to be developed in the near future. The NRPA provides advice to operators on monitoring and sets requirements in authorisations for monitoring programmes to be compatible (as much as possible) with international guidance (e.g. IAEA Safety Standards Series RS G-1.8). The monitoring requirements are based on the authorised source term, consideration of additional radionuclides that could be potentially important for specific processes, and taking account of different environmental pathways. Each monitoring programme is therefore site-specific. It is up to the facilities with authorisations to decide on the appropriate details of the monitoring programmes, but the expectation is for the programmes to be proportionate with risk of impacts on humans and the environment, taking into consideration the costs associated with monitoring and to represent past, present and future discharges.

With the regulatory framework in Norway requiring a holistic approach to risks, operators are required to comply with NRPA monitoring requirements, but also the requirements of other authorities responsible for the regulation of non-radioactive hazards. The monitoring programmes should therefore be optimised with regard to the number of samples and sampling frequency to meet the different requirements whilst minimising costs. Monitoring is required to be undertaken to meet all necessary quality standards and to address stakeholder and public expectations and concerns. All monitoring plans are sent to the appropriate regulatory body (e.g. NRPA) for approval prior to implementation. Monitoring results must be sent to NRPA yearly (or after other approved time periods) with final reporting being linked to operational activities.

A national road construction project in an Alum Shale area was presented as an example. The project has recently completed after five years of construction in the County of Hadeland, which is an Alum Shale-rich area, which, in turn, is associated with variable U-238 concentrations. The project included road and tunnel construction. Acid leaching is an issue for Alum Shales when in open-air oxic conditions. Contamination of soils could also result from construction activities.

The construction project was regulated by both NRPA and the Norwegian Environment Agency. Approximately 100,000 m^3 of Alum Shales with U-238 concentrations exceeding legislative levels for radioactive waste were excavated as a result of tunnel construction. Rather than classifying the excavated shale as waste, reuse of shales in road construction was planned. The reuse of the shales had to be demonstrated to be safe and required their use to be controlled to ensure the shales were in anoxic conditions below underground water levels to maintain favourable redox conditions thus prevent acid leaching.

The reuse of the Alum Shales was a new situation and the NRPA set requirements for a monitoring programme that was to include pre-construction monitoring activities to obtain data on the pre-state conditions and background concentrations. The monitoring programme was required to then continue throughout the active construction period and for a further three year post-construction period. The Norwegian Public Road Administration was required to define and justify to the NRPA:

- the choice of sampling points;
- the radionuclides and other parameters that would be monitored;
- the frequency of monitoring; and
- all methods for sampling across all steps in the proposed environmental monitoring programme.

There was lots of discussion between the Administration and NRPA during the development of the programme with the approved programme including:

- water from a river and three streams in the vicinity of the tunnel construction area;
- water collected in the construction water collection system and in the purification system;
- groundwater; and,
- sediment and biota (fish, benthic invertebrates and plants).

Samples were monitored for U-238, Ra-226, Po-210 and Pb-210, along with heavy metals, pH, turbidity etc. The frequencies of sampling were variable with the greatest frequency being associated with construction site discharge points. On-site experiments were also conducted to investigate leaching potential and uptake by biota etc. It was, therefore, a very comprehensive monitoring programme that was undertaken.

Results from monitoring have shown some leaching from excavated and temporarily stored Alum Shales, with consequent increases in uranium activity concentrations in local water bodies during the excavation period, but these were below regulatory limits. Since construction activities ended, activity concentrations have decreased to background levels. There was no measurable accumulation in biota and no adverse biological effects were observed.

This proved to be a very comprehensive and successful monitoring programme. A final report on the programme is due to be submitted in June 2018.

With the plan for NRPA to develop a guidance document for monitoring, noting that monitoring programmes will be very site-specific, questions arise as to how to provide guidance on the level of detail required in terms of monitoring and how uncertainties can be reduced. Furthermore, where there are multiple hazards, thought will need to be given as to whether separate monitoring programmes would be required or whether a single programme can be put in place to address the various hazards that may be present. Again, these are very site-specific issues and will be challenging to address in the development of monitoring guidance.

Discussion

No percentage increase above baseline acceptance levels are set for monitoring programmes. Rather, NRPA requires best practice in analysis and impact assessment to be employed with NRPA then deciding on whether the assessed level of impact is acceptable. This is supported by internal modelling studies and drawing on international guidelines etc. Active discussion between operators and NRPA is encouraged and a reasonable approach is taken to ensure programmes are proportionate to the levels of risk, irrespective of whether risks are associated with radioactivity or other hazards.

3.2 RADIOLOGICAL SURVEILLANCE IN BELGIUM

Geert Biermans presented on behalf of FANC.

In Belgium, the Federal Agency for Nuclear Control (FANC) has both national and international obligations with regard to monitoring. International obligations arise in relation to the Euratom Treaty, which requires Member States to undertake independent and representative monitoring programmes for radioactivity and report results to the EC, and in relation to OSPAR, which requires releases of radioactivity to the marine environment to be reported and for coastal areas to be monitored.

Under the national FANC law of 1994, FANC is required to undertake radiological surveillance of the environment and human exposures in relation to both natural and artificial radionuclides. Radiological surveillance programmes include site surveillance of licensed operators to evaluate compliance with license requirements, general surveillance of the environment and specific surveillance programmes such as those relating to NORM, radon and legacy sites. There is also monitoring for orphan sources. There are two main aspects to radiological surveillance of the Belgian territory – sampling within an environmental monitoring programme and an online measurement and alert network for real-time activities. FANC is independent of the Government, but is required to cover the costs of the surveillance programmes. The cost of meeting all monitoring obligations is around 2 million Euros per year.

Landfills in Belgium were not originally designed to receive NORM waste, but were focussed on the disposal of either hazardous, non-hazardous or inert waste. Each landfill has waste acceptance criteria established, along with monitoring programmes to ensure appropriate leachate management and to ensure that controls for the protection of soils and water are performing appropriately. However, in the past, landfills were not properly regulated and NORM could be disposed of (prior to 2013) with decisions being made on a case-by-case basis. Prior to the 1980s, all wastes were routed to landfill and no records were kept on what was disposed. Since 2013, the disposal of NORM has been regulated and exemption/clearance values have been defined. Where activity concentrations exceed clearance values, NORM must be disposed of by a registered operator.

The regulation of landfills falls to the different regional authorities and, as such, FANC is required to align the approach to the regulation of NORM disposal with the different regions and set criteria for each landfill. The criteria are set as average activity concentrations that can be consigned to the landfill. Annual reports on consignments are required to be submitted to FANC by landfill operators. Portal alarm monitoring is also in place to detect any higher activities such as medical waste. Between 2012 and 2017 the portal monitors have made over 1,600 detections.

Landfills that accept NORM have been subject to screening under a NORM landfill monitoring project that covered 10 landfills for non-hazardous waste (not registered for NORM), 3 landfills for hazardous waste (registered for NORM) and 5 old municipal landfills. Measurements include gross-alpha, gross-beta, K-40, uranium and Ra-226 in leachate, discharge water, surface water and groundwater. The first campaign took place in 2012 and no reference levels (i.e. discharge limits) were found to be exceeded, but there were some issues identified, such as 1.2 Bq/l Ra-228 being measured in leachate samples and Ra-226 has been measured in groundwater associated with a manganese production residues landfill. There have also been several instances of gross alpha and beta being higher than screening values, but when compared against background values (which are very variable across Belgium), no significant difference is observed. Overall, no significant difference was observed between leachate from hazardous and non-hazardous landfills. However, concentrations of potassium salts can be high which can affect monitoring results for alpha resulting in a high detection limit and implications for decision making.

For one non-hazardous landfill, leachate monitoring in 2011 showed that Ra-228 activity concentrations were close to discharge limits. Subsequent monitoring has indicated a steady decrease in activity concentrations. By 2016, the activity concentrations were considered trivial. The monitoring therefore suggests a past peak in Ra-228 concentrations. For discharge water, gross alpha and beta are usually below levels of concern, but occasionally higher activity concentrations are measured as compared with upstream surface water. This is also the case for uranium concentrations. Whilst the increased activity concentrations that have been measured in the past are not radiologically significant, they are notable. In many instances, samples are taken of leachate for analysis of both radioactivity and chemicals and, in most instances, issues arise as a result of the chemicals present. Decisions can therefore largely be made with regard to the chemicals present, but with advice being given by FANC on the radiological aspects.

Older landfills do not have protective barriers to contain waste or leachate collection systems. As such, radioactivity in groundwater has been measured in varying quantities, including non-trivial uranium concentrations in some instances and Ra-226 concentrations of the order of 0.25 Bq/l have been measured. These older landfills have been capped and no longer have designated operators and the history of such sites is often not known in any detail and must therefore be researched. For some sites, illegal dumping of industrial wastes is known to have occurred, such as at the Fond du Houtia landfill. This was used as a municipal landfill between 1973 and 1983, with illegal dumping taking place until 1989. The remediation of this landfill involved capping of the site and environmental monitoring continued. No action was taken to address the contamination present within the landfill. Monitoring of groundwater at this site has indicated high levels of uranium, which poses a chemical rather than radiological risk. Decisions are required on whether uranium levels are safe or whether further action is required.

In addition to landfill sites there are a number of historical industrial sites in Belgium associated with NORM contamination (e.g. steel and chemical industries and coal mining sites). These sites were not regulated to current standards and are now being brought under regulatory control. For example, there are several phosphogypsum production sites in Belgium. At one site, two phosphogypsum disposal stacks are present. One has been correctly disposed of following neutralisation of the phosphogypsum. The other stack was not subject to neutralisation prior to disposal and acidic conditions have resulted in leaching. The stack was also unstable, requiring regional intervention to protect a town. Since 2000, leachate monitoring has taken place. Leachate from the neutralised stack has trivial radioactivity, but that from the phosphogypsum disposed of in acidic conditions has considerably higher activity concentrations (e.g. 0.3 Bq/l gross alpha as compared with 0.16 Bq/l in the neutralised stack leachate).

Monitoring has also been undertaken on groundwater in the vicinity of a historical ferro-niobium extraction site that was active in the 1960's and 1970's. The site is associated with slag up to 60 Bq/g Th-232 and 12 Bq/g Ra-226 and patchy contamination over the site, including from heavy metals. Groundwater is impacted as a result of the historical contamination at the site.

Groundwater contamination has also been observed at historical uranium production sites. In Brussels there was a factory for the production of uranium salts that was operational from 1925 to 1943. The factory was located in what is now the centre of the city. Whilst the factory has completely gone from the site, a few years ago, monitoring of tap water in a local school showed that there was uranium contamination. This monitoring triggered the need for immediate remediation from a radiological perspective. It is not known what triggered the sudden occurrence of tap water contamination.

The radiological monitoring programme has therefore identified some operational landfills where there are observable impacts in relation to uranium and Ra-228 in leachate or surface waters, although no reference values have been exceeded. It can be concluded that there is no issue at these sites in terms of radiation protection, but there may be issues in relation to chemicals present. What has been an unexpected finding is that there is no observable difference between ordinary landfills and those for hazardous waste that are authorised for the disposal of small quantities of NORM. Furthermore, with the exception of uranium production, the impact of NORM disposal sites on groundwater does not differ significantly from ordinary landfills. Overall, legacy facilities tend to have a greater impact on groundwater than waste disposal sites.

In older landfills, no bottom liners are present, nor leachate collection systems. As such, groundwater contamination is evident in many instances with uranium being detected. In many instances it is the chemical toxicity of uranium that is the issue, rather than the radiotoxicity. Nonetheless, there can be issues around the assignment of responsibilities.

Discussion

Collaboration between regional authorities and FANC on monitoring has proved to be an efficient means of obtaining samples, ensuring the programmes are as cost effective as possible.

In the example of the school where tap water was found to be contaminated, both a chemical and radiological issue was present although the chemical toxicity risks were greater. As such, the regional regulator took the lead in public consultation and communication. Decisions around whether regional authorities or FANC take the lead in communication are made on a case by case basis. Irrespective of who takes the lead, agencies work together to ensure an integrated and consistent approach.

3.3 POSIVA'S ENVIRONMENTAL MONTORING PROGRAM AND PRESERVATION OF BASELINE SAMPLES FOR THE FUTURE

Tiina Sojakka presented on behalf of Posiva.

Posiva has coordinated an environmental monitoring programme since 2004 around Olkiluoto, the site chosen in Finland for the disposal of spent nuclear fuel, that covers aspects such as rock mechanics and geochemistry etc. as well as the surface environment. The objectives of the programme have been:

- to monitor the environmental impacts of final disposal and related activities in order to fulfil the requirements of environmental licencing and other regulatory criteria;
- to map land-use changes in the area that can affect the results of other monitoring and research activities in the area (e.g. how construction impacts on the site); and,
- to produce input data for radionuclide transport modelling regarding the surface environment.

The monitoring programme has been regularly updated with the most recent update being in 2012 (described in Posiva Report 2012-01) and covering the period from 2012 to 2016. At the end of 2016 there was a data lock for biosphere modelling and regular monitoring studies such as game statistics, water quality parameters, forest investigations and element analyses all ended at this time. The monitoring programme since has focussed on evaluating the impacts of construction, but a new programme is about to be implemented for the operational repository phase and planning for this is being progressed.

The construction phase monitoring programme has included a wide range of parameters. Noise measurements are regularly taken at set points to evaluate how construction works may be affecting the local environment (the repository site is close to a nature conservation area so impacts must be assessed). Changes in land use have also been evaluated through aerial photos that are taken every two years. Land uplift has also been monitored over 5 to 10 year intervals.

There are a number of surface waters in the vicinity of the site and it has been necessary to evaluate the impact of construction on these. Outlet water from ONKALO have been monitored and compared against action limits for surface waters (i.e. pH and suspended solids) along with parameters such as nitrate, nitrite, sulphate and conductivity. The monitoring of nitrate is linked to explosion works for tunnel construction. Where variations in parameters are detected, further analysis is undertaken to identify reasons.

Waters associated with excavated rock heaps are also monitored to ensure that pH and suspended solids are within acceptable limits. To date, no exceedances have been recorded. Automatic surface water monitors have also been installed around the site. These constantly monitor surface water run-off and transmit a wide range of data such as ammonia, dissolved organic and inorganic carbon, phosphate and sulphate concentrations along with parameters such as conductivity, temperature, pH etc. Recently, high sulphate measurements have been recorded and these are subject to further investigation.

Weather monitoring equipment has been installed around the site to provide data on temperature, precipitation, wind speed and direction, humidity and photosynthetically active radiation. Snow and ground-frost measurements have also been made. All of the data obtained related to weather/climate supports hydrological considerations in safety assessments.

A number of private drilled wells have been subject to monitoring with water samples being taken annually for analysis to ensure that construction activities are not impacting on groundwater in the area. The surface level of groundwater in the wells has also been monitored twice yearly. The water quality of groundwater is naturally low due to the island location such that chloride levels are high. Olkiluoto is not, therefore, suitable for drilled wells for drinking water at the current time.

Monitoring of the coastal area used to be undertaken annually, but has reduced recently to monitoring every three years. Benthic water samples are taken to investigate the relationship between groundwater and sea water. Flora and fauna studies are also undertaken about every 10 years to ensure there has not been any change in biodiversity in the area as a result of construction activities.

In addition to construction phase monitoring activities, an environmental radioactivity baseline study has been made. Nuclear facilities are obliged to make such studies prior to the construction or operation of any new nuclear facility. Prior to 2017, this study was part of the overall environmental monitoring programme, but became its own project from 2017. The results of this baseline study will be used to inform the operational monitoring programme.

The results of the different aspects of the monitoring programme are reported in a series of annual reports. Published reports are all available from www.posiva.fi/en/databank, and include results of monitoring at Olkiluoto in reports dedicated to environmental monitoring in general, forest monitoring, and game statistics. There are also campaign-based reports on birds and insects and on reference mires and rivers.

In terms of sample preservation, most analysed terrestrial soil and plant samples from permanent monitoring networks on Olkiluoto Island are maintained in an environment specimen bank in northern Finland. The rest of such samples are temporarily archived at the Natural Research Institute Finland. Posiva also maintains duplicate and additional samples at their laboratory in Eurajoki to allow for additional laboratory analysis if required.

The northern Finland Environment Specimen Bank was established in 1994 by the Finnish Forest Research Institute (now merged into Natural Resources Finland). The facility is comprised of nine fireproof storage rooms that are focussed on long-term (>10 years) storage. There is real-time monitoring of air temperature and humidity inside the storage rooms and storage boxes. Samples stored at the facility from Posiva's monitoring programme are summarised in Table 3. Samples stored at the facility have been subject to controlled drying and most are stored in powdered form. The samples can be used as reference material to describe the conditions at the site prior to operation of the spent nuclear fuel repository. The samples may also be used, if required, for repeat analysis, to confirm the quality of past analysis or to allow enhanced analysis using new and improved techniques in the future.

Table 3. Posiva's samples in the Environment Specimen Bank.

Material	Collection period
Needles	2003 – 2007
Needles, leaves	2005 – 2006
Litter fractions	2004 – 2008
Plant species samples	2008
Mineral soil, humus	2005
Mineral soil, humus, peat	2007
Peat samples	2005
Tree leaves (not milled)	2005
Plant species samples	2005
Needles	2010
Litter fractions	2009
Tree samples (wood, bark)	2008
Tree samples (foliage etc.)	2008
Litter fractions	2010 – 2012
Humus samples	2008
Litter (remaining fraction from branch traps)	2008 – 2013
Litter fractions	2013
Humus samples	2015
Leaves	2015

For samples stored in Posiva's laboratory, a sample register is maintained that details all collected samples between 2005 and 2015. Samples are stored as either dried or ashed material in paper bags that are labelled for identification. Both plant and soil samples are stored, including aquatic plants and mosses from Olkiluoto and reference areas (mires, lakes, rivers), berries, cultivated plants, shovel-dug pit soils, cropland soils and soil samples relating to fauna studies that have been undertaken. In addition to dried samples, there is also a freezer near the laboratory that is maintained at a temperature of -24 °C. Samples stored in the freezer include peat from reference mires, sediments from reference lakes and mires, and some animal samples such as fish and mussels from the reference lakes.

The monitoring programme in the earlier days had an operating budget of around 1 billion Euros annually, which reduced to around a third following the revisions to the monitoring programme since 2016. The programme employs a research coordinator, field staff, consultants and laboratory staff. Sample storage at the Environment Specimen Bank costs less than 10,000 Euros per year.

Discussion

The benefit of more numerous samples being taken in both space and time was recognised when planning the monitoring programme. There are, however, significant cost implications associated with monitoring and analysis and a balance was therefore needed. This was, in part, addressed through the use of automated measurement equipment that then triggered more event-based sampling. In addition, sampling locations were usually selected based on a wider, but lighter, earlier survey

The annual budget figures include costs associated with equipment maintenance, sample collection and analysis plus personnel costs.

3.4 SKB AND THE ENVIRONMENT

Ulrik Kautsky presented on behalf of SKB.

The environmental monitoring programme undertaken by SKB, which initially covered two sites (Laxemar and Forsmark) had several objectives:

- to document the initial state and minimise environmental impact during site investigation;
- to develop site understanding;
- to begin developing long-term survey data sets;
- to collect data in support of safety assessments and environmental impact assessments; and,
- to collect data for other studies, such as boundary conditions and for calibration.

The main initial driver for the monitoring programme was to obtain data in support of the safety assessment and the biosphere assessment team took the lead in developing the programme. Wherever feasible, an integrated approach was taken to monitoring to meet the various objectives.

To inform the development of the monitoring programme, a matrix analysis was made to determine what needed to be considered in the surface environment. This has been reported in SKB R-00-09 (in Swedish, but currently being translated to English). The matrix sets out the variables (e.g. contaminants, fauna, flora etc.) that were evaluated in terms of what objectives they met (e.g. supporting the safety assessment or environmental impact assessment). Spatial (regional, site specific etc.) and temporal (seasonality etc.) considerations were also set out along with evaluations of who could provide the data (e.g. whether data sets were already available from other monitoring programmes) and/or study types that could provide the required data and the skills required for obtaining the data. Thought was also given to the programme phase that monitoring related to, such as whether monitoring was required when the system was undisturbed or during the operational phase etc. A graded scoring system was applied. The matrix provided justification from the outset for what was to be measured and why and whether repeat sampling and/or sample archiving would be needed.

Thoughts on monitoring were also informed by a paper[a] that considered the fact that there is constant change in nature, such that there is no 'baseline'. In light of this, thought was given to how different areas/sites could be compared in order to detect impacts. The use of several sites for comparison can address this, but there is a need to monitor each over time to obtain time-series information both before and after activities in order to gain an understanding of variability versus impact. It is not possible to just compare single points in time to determine impact.

The monitoring programme was also informed by regulatory requirements. SSM required SKB to assess the biosphere as it is today and to undertake a quantitative assessment for the first 1,000 years based on a realistic understanding of the site. There was also a requirement to assess the effects on the environment from the repository construction. This was emphasised by a new environment protection code that placed more requirements around environmental impact assessments. Furthermore, in moving to a real site from generic assessments, new questions tend to arise, many of which are focussed on the surface environment since this is what people relate to and the monitoring programme can help to address these questions.

A literature review was undertaken initially to identify those data that were already available and numerous relevant data from other monitoring programmes were identified. For example, national monitoring programmes were identified that could be adapted to the site and/or used as a point of comparison.

Surveys were then planned with reduction of impact being a key consideration. For example, access maps were made to target surveys in key biotopes, in areas that were accessible, and areas that would be less invasive, e.g. avoiding disturbance to endangered species and avoiding areas that needed to be preserved in a pristine condition for later monitoring. The maps included also advice to locate for example the bedrock drillings in areas with a lesser degree of environmental disturbance. The access maps were improved as more information was obtained.

There is a large list of Red List species in Sweden and this led to some issues and challenges. For example, the access maps were misplaced seven years into monitoring programme as a result of staff changes. With the loss of the maps, the surface facilities were planned for an area inhabited by pool frogs, which are a Red List species. A learning point was therefore the importance of undertaking field checks and continuously updating the preserved knowledge base as more information/data becomes available. This should include information on land ownership of survey areas and habitats present in which sensitive species could exist.

Considerable costs had been incurred on the programme to this time (much of which was associated with laboratory analysis costs) and it was necessary to slim the programme. Further cuts were made a further 11 years into the programme. An evaluation has been made of the data available from the monitoring programme in support of the HLW disposal safety case and data gaps were identified. The findings are reported in SKB Report TR-15-01 on the evaluation and recommendations for the monitoring programme update, which sets out what monitoring should be done in the forward programme, based on past experience.

Seventeen years after the start of the programme, the SR-Site safety assessment was put to the environmental court. The issue of Red List species was raised in the court and, specifically, why SKB

[a] Stewart-Oaten, A., Murdoch, W.W. & Parker, K.R. 1986. Environmental impact assessment: "Pseudoreplication" in time? Ecology 67(4): 929–940.

had selected a site that had the highest number of Red List species in Sweden present. The number of Red List species at the site resulted from the monitoring programme, which had identified many of the species present. Indeed, SKB was the highest reporter of Red List species during the time of the monitoring programme. The high number of species identified at the site was therefore down to the site investigation programme.

The Water Authority raised a question about nitrogen releases from blasting and the implications of this for eutrophication of the Baltic Sea. SKB had a number of coastal monitoring sites around Forsmark, with data being supplemented by other monitoring programmes carried out further from the coast. Together, these data provided information on seasonal variation in nitrogen (and phosphorus) over a 10-year period. The traditional view had been that phosphorous would be the limiting nutrient in the Baltic Sea, but the data showed that it was in fact nitrogen that was limiting. This was not ideal, since the release of nitrogen from blasting would have to be prevented. Hydrodynamic modelling was therefore undertaken on nitrogen movement, informed by site investigations and site understanding, which demonstrated that nitrogen would not impact the Baltic Sea as a result of blasting activities. The knowledge base developed by SKB as a result of the site investigation programme was a huge positive for the environmental court and was recognised as being worth every penny. Whilst the cost of the surface investigation programme was high, it is insignificant compared with geological characterisation and the drilling of boreholes and running the measurements and sampling in them with the highly specialised equipment needed for that.

The monitoring programme has been slimmed to address remaining data/knowledge gaps and to focus on particular interest areas. Of the current annual monitoring budget (around 500,000 Euros), 45% is spent on ecological monitoring, 45% is on chemical monitoring/analysis and 10% is on surface hydrology and meteorology. There are two people employed full time. The current costs would be significantly higher at present if the site investigation programme of the past had not delivered so much.

In summary, careful planning can significantly reduce costs and ensures integration of different needs, but it is vital that the environment receives the focus deserved. Plans need to be in place to ensure that knowledge is maintained and that appropriate archives are kept to support future needs and to allow impacts to be assessed, recognising that there are no constant baselines.

Discussion

A number of samples are preserved, including frozen water samples. Such sample preservation requires power supplies to be maintained along with alert mechanisms in the event of any operational issues such as power outages. Responsibilities also need to be assigned and adequate knowledge instilled around the importance of maintaining the operation of storage facilities/equipment.

Being open around what is being done at a site and regularly publishing information / data can be very beneficial in promoting public understanding. The environmental court findings demonstrated that a high level of public confidence had been achieved in this case.

3.5 ENVIRONMENTAL MONITORING STRATEGY FOR CIGÉO COMPRISING ENVIRONMENTAL SPECIMEN BANKING

Yves Thiry presented on behalf of Andra.

Andra was created in 1991 as a result of a French Waste Act and is the organisation responsible for radioactive waste interim storage and disposal in France. Andra currently manages two operational surface disposal sites in France and is working toward a license application for the construction and operation of the Cigéo deep geological disposal facility for high and intermediate long-lived radioactive wastes. In 2005, a dossier was published that established, in principle, the feasibility of deep disposal of radioactive waste. Geological disposal was formally accepted in 2006 as the preferred option and the location for a geological disposal facility was set. A license application submission was originally planned for 2017, but has been delayed until mid-2019. It is expected that it will be at least 3 years following the license submission before a final regulatory decision is made on the facility license.

The location of the Cigéo facility is north-eastern France. The facility is planned to be located at a depth of 500m in the Callovo-Oxfordian layer in a clay rock formation. Two surface facilities are planned. One will be for waste conditioning. The other will be a construction support facility for the repository. The site is also the location of an underground research laboratory and the long-term environmental observatory (OPE), which is for the long-term storage of environmental samples.

The site is within a rural landscape and is subject to a temperate oceanic climate. There is a low population density and no large cities are present (the nearest city is between 40 and 50 km from the site). Industry is low in the area. The topography of the area is of soft relief with slightly sloping plateaus intersected by rivers. Predominant rural activities in the region are agriculture (primarily wheat, barley and soybean production and grassland). Around 35% of the land area is forested.

The OPE was started in 2007 as a specific tool for long-term monitoring of a rural area impacted by an industrial project. The facility includes an environmental specimen bank to preserve samples of the current baseline and to allow for retrospective assessment. There were three main objectives for the OPE:

- to characterise the initial state of the environment (around 10 years prior to the start of the Cigéo project);
- to track the evolution of the site via key indicators of ecosystem functioning during the operational phase (>100 years); and
- to understand and distinguish between the various sources of environmental changes (local, regional and global) and pressures (natural and anthropogenic).

The environmental monitoring area is around 900 km^2, centred around the area that will be used for the Cigéo repository. Observation points are systematically distributed throughout this area and include continuous water quality monitoring stations, a flux tower, three biogeochemical forest stations, one atmospheric station and two agricultural stations. Satellite and aerial observations are also made across the site with data from the site being coupled to GIS data. The monitoring programme is not conducted in isolation, it is integrated with international and national networks. A memory of the programme is being established by maintaining good records and databases. The monitoring programme has been developed in relation to the landscape and so includes forests, atmosphere, soils, the hydrosphere, land use and biodiversity. Socio-economic data are also gathered.

A collaborative network has been set up involving numerous organisations both within France and internationally that have expertise in different aspects of environmental survey programmes, from environmental banking and databases through to ecosystem monitoring at a territory scale. This is important for understanding different scales (local, regional and global) and for inter-comparisons. For example, soils from the study area have been compared with soils across France to gauge soil quality in the area. Earthworm biodiversity has also been compared against national data, showing that the diversity is within the national range for the number of species. Atmospheric C-14 surveys have also been integrated, with comparisons made against reference data from Switzerland and the Netherlands.

Observed deviations are largely due to the use of fossil fuels with peaks being observed in the winter due to increased carbon emissions and between urban and rural locations. Water quality monitoring at the site has been integrated with data from a national monitoring programme. There is evidence of water pollution as a result of agricultural activities in the local area as compared with less agriculturally active locations.

The OPE environmental specimen bank (ESB) is designed as a complimentary tool with the objective of keeping a memory of the environment that will allow for retrospective analysis of the local food chain and bioindicator samples, as well as project-specific interests such as agricultural station samples. The storage of samples will also allow analyses to be made using new techniques as they develop into the future. A further aim of the ESB is to involve and inform local stakeholders through a dedicated open access visitor centre. The ESB may also support future specific programmes requiring environmental samples and could be used for the storage of samples from other programmes.

Between 2007 and 2012, the OPE project was focussed on the gathering and development of expertise, on the design and construction of the building and on the design of the sampling strategy. The facility was completed in 2013 with the first sampling campaign being undertaken in 2014 with the objective being to test the infrastructure. The first Cigéo reference state monitoring took place in 2015.

The sampling strategy was used to inform on the facility dimensions. It is intended that samples will be stored for at least 100 years. Based on the current sampling plan the building is designed to accommodate at least 20 years' worth of samples. However, it may be necessary in the future to reduce the sampling intensity to comply with the amount of storage available.

Prioritisation of environmental samples has been based around a step-by-step process. Priority has been given to a selection of raw and processed samples representative of local production or bioindicators of the chemical quality of the environment. Costs influence the frequency of sampling and overall intensity and the sampling plan has been developed in light of the envisaged costs. The programme will be kept under review and revised as required.

The OPE is within an area of Protected Designation of Origin for the cheese *Brie de Meaux* and a cheese dairy is located within the OPE reference area. This has therefore been taken into account in the sampling plan with locally produced milk being sampled. Four dairy farms have been selected along with one cheese dairy. A control dairy farm has also been selected. The current sampling frequency is four times per year with a composite annual sample for each dairy farm being created.

Andra is part of an international group on environmental specimen banks, which has been very useful in informing on optimised strategies for sampling and the preservation of samples. This has helped optimise the sampling programme and informed on quality assurance of sample processing.

Changes in the environment are expected to occur over time. For example, construction of the OPE facility has resulted in changes to the surface environment. Further impact will result from Cigéo construction and associated infrastructure. There will also be more diffuse changes, such as those associated with climate change, social change and changes in agricultural practices. The monitoring programme aims to integrate these different aspects within a scientific approach that will also address local perceptions and expectations about the environment from local stakeholders.

Discussion

No decisions have yet been made in relation to monitoring during the post-closure phase of Cigéo. It is likely, however, that the current monitoring and sampling preservation approach will be adapted to address post-closure monitoring needs.

4. CURRENT AND FUTURE WORK PROGRAMMES AND ACTIVITIES

Progress in BIOPROTA projects was presented prior to presentations and discussions around possible future activities. Presentations around current and recently completed BIOPROTA projects and planned related activities are summarised in Sections 4.1 to 4.3. SSM then gave a presentation on a planned programme of C-14 measurements in the marine environment in Sweden that may inspire BIOPROTA collaboration and/or subsequent model-data comparison studies, as summarised in Section 4.4. A table is then presented in Section 4.5 that summarises ideas for possible future collaborative projects and activities identified during discussions.

4.1 BIOMASS METHODOLOGY: PROGRESS AND FORWARD PLANS

Russell Walke presented on behalf of the Technical Support Team for the BIOPROTA project.

The BIOPROTA project on enhancement of the IAEA BIOMASS methodology began in 2016 and is running in parallel with working group 6 (WG6) of the IAEA MODARIA II programme. Four workshops have been held to date that have focussed on sharing knowledge and experience in support of the methodology enhancement.

Collaborative programmes relating to biosphere assessments for radioactive waste disposal safety assessments have been undertaken for some time, leading to the development of the BIOMASS methodology. The BIOMOVS II programme ran from 1991 until 1996 with some consideration given to whether common biosphere models (reference biospheres) could be developed as measures of potential impact. It was quickly concluded that it was impractical to develop 'reference' models for biosphere assessments, due to differences in climates, disposal concepts etc. Instead, the idea of a reference biosphere <u>methodology</u> was promoted and a list of features, events and processes (FEPs) was developed to support harmonisation throughout different assessment programmes. The idea of a biosphere methodology was then taken further within the subsequent IAEA BIOMASS programme, that ran from 1996 to 2001. The methodology that was developed within this programme has been widely accepted and applied as useful guidance for assessments.

The BIOMASS methodology is presented as a linear work flow (shown in Figure 8), but the need for iteration and revision is emphasised. The starting point in the method is the assessment context, which explains clearly what is being assessed and why; in quantitative assessments, this becomes what is being calculated and why. The context guides assumptions necessary in the assessment. The second stage is to identify and justify biosphere systems that will be represented in assessments that would then be taken forward into the biosphere description stage. There was recognition during the initial methodology development of the potential for non-human biota to be an assessment endpoint, but this was not taken further at that time. Rather, the focus of the linear work flow was on defining human potential exposure groups (PEGs). The methodology then progresses to model development and calculation. Lists of FEPs and principles for data selection, biosphere system identification and critical group selection all feed into the methodology.

Since the publication of the methodology in 2003 there has been considerable experience internationally on the practical implementation of the method, on characterising sites, and integrating ecosystem understanding within assessments. There have also been scientific developments relating to aspects such as climate change and landscape evolution, and on assessing impacts on non-human biota. There has also been greater recognition of non-radioactive contaminant releases from waste disposal facilities and advances in understanding and modelling of radionuclides with complex behaviours (e.g. redox-sensitive radionuclides).

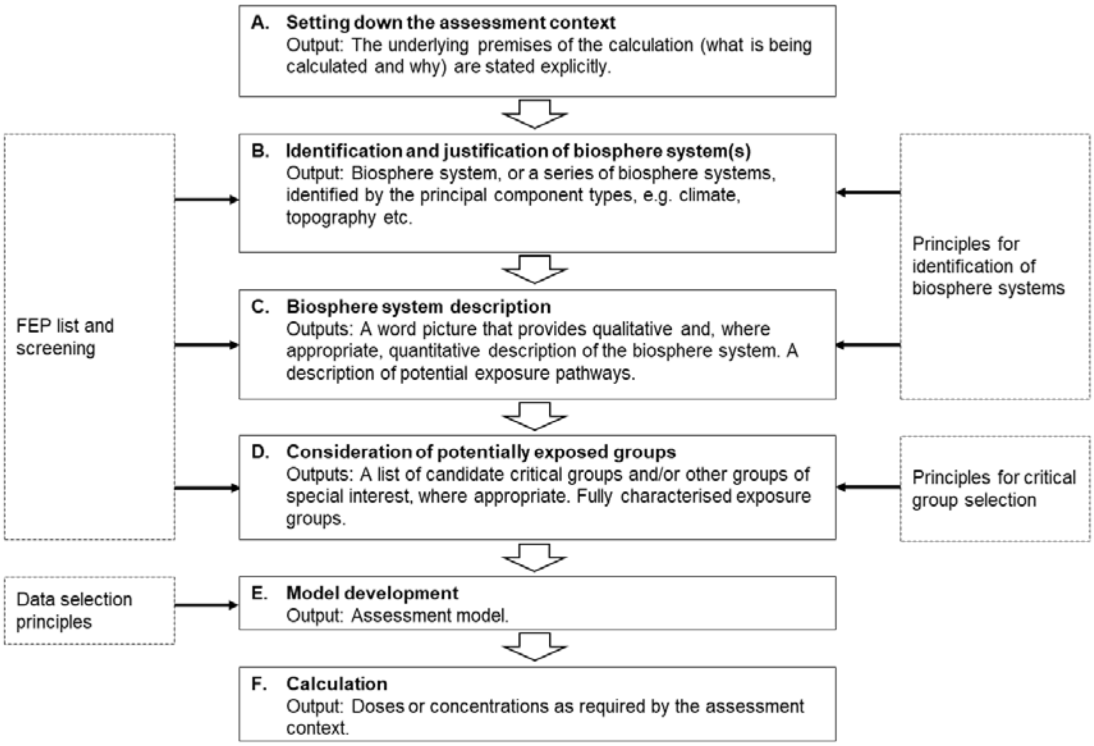

Figure 8. The BIOMASS methodology [IAEA, 2003]

The BIOMASS methodology has been shown to be useful and robust, but the need to revise and enhance it in light of these various developments was recognised. As such, a proposal was submitted to the IAEA for WG6 to focus on enhancing the methodology within the MODARIA II programme. This programme began in 2016 and will run until the end of 2019. It was recognised that real technical effort would be needed to support the methodology enhancement and, as such, a parallel programme was initiated within BIOPROTA to provide this input.

The BIOPROTA project was initially due to run from 2016 to 2017 with an interim report delivered at the end of 2017. The usefulness of the technical support to the overall enhancement project was recognised by the BIOPROTA project sponsors and the aim, therefore, is to now provide technical support until the end of the MODARIA II programme in 2019.

The BIOPROTA project, in addition to the interim report, has provided input to the associated workshops, helped facilitate those workshops and has delivered a series of workshop reports, summarising the presentations and discussions during each of the project workshops that have been held jointly between BIOPROTA and WG6. The final interim report was published by SKB in 2018 as report R-18-02. The report is 'interim' and includes a number of place holders where work is still to be done.

An updated methodology diagram will be a key deliverable for the enhanced methodology. Some refinements have been made to date with some restructuring of the initial methodology to highlight links to the overall safety case (Figure 9). The identification and justification of the biosphere(s) and specification of biosphere(s) are grouped, as are various aspects that fall within development of biosphere exposure model(s). Further refinement of the methodology figure is planned and comments and suggestions are invited.

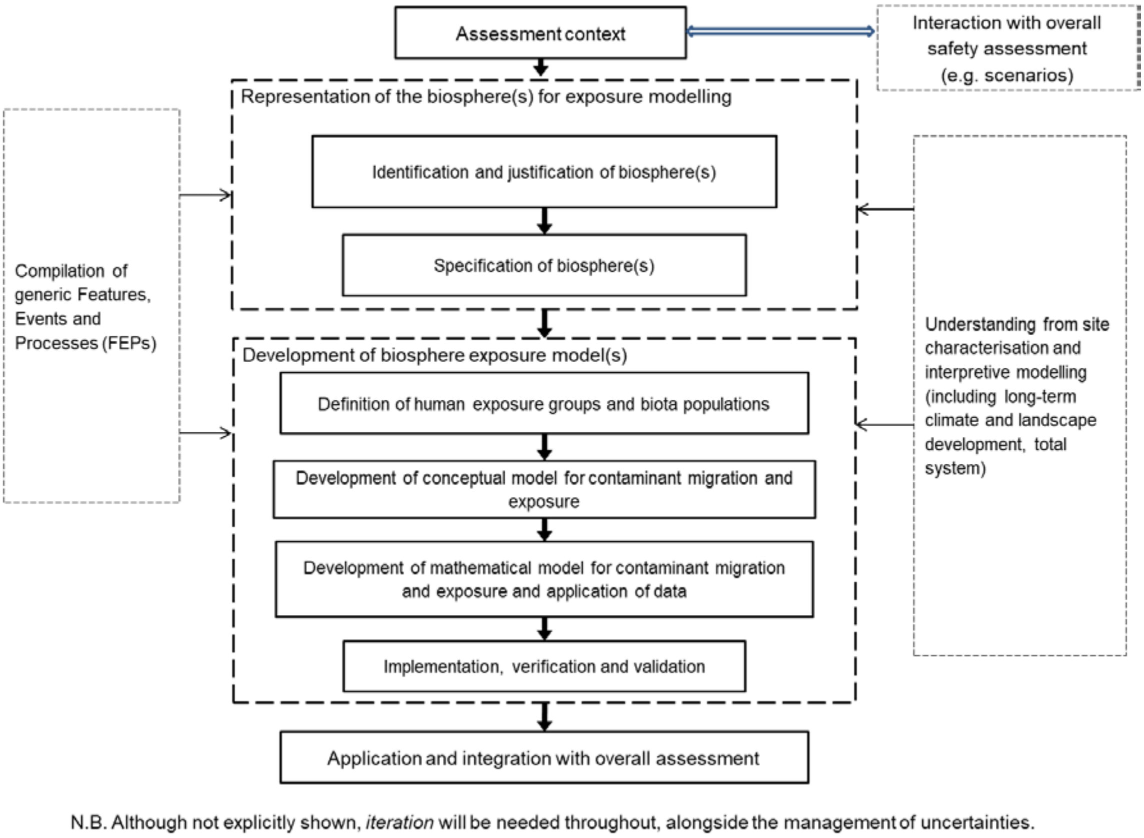

Figure 9. Revised (interim) BIOMASS methodology [from SKB R-18-02].

A proposal for continued BIOPROTA technical support to the enhancement of the methodology has been circulated to BIOPROTA members. The proposal covers technical enhancements and workshops in 2018 with the aim of finalising the updated methodology as a BIOPROTA report that may be taken as a contribution to a final WG6 report in 2019. Continued support in 2019 is anticipated, but is not included in the current proposal. Support to the project is invited and the project plan for 2018 will be revised to reflect the level of funding available.

Discussion

Verification and validation are terms used in the revised methodology figure, but whether it is feasible to validate and/or verify long-term models can be questioned. Whilst it is not feasible to validate models for the long-term, it is possible to validate some components and the enhanced methodology will focus on these aspects.

A questionnaire has been distributed by WG6 on the definition of PEGs and some feedback has been received from working group participants. Having a wider range of responses would, however, be beneficial. The questionnaire will therefore be distributed around BIOPROTA participants to invite further responses.

4.2 ISSUES AFFECTING THE ASSESSMENT OF IMPACTS OF DISPOSAL OF RADIOACTIVE AND HAZARDOUS WASTE

Graham Smith presented on behalf of the Technical Support Team for the BIOPROTA project.

The project 'Issues affecting the assessment of impacts of disposal of radioactive and hazardous waste' completed in 2017. The project followed from two previous workshops related to this topic that noted the need for a holistic approach that would support consistent assumptions and criteria for risk evaluation that would, in turn, support proportionate resource allocation. It was recognised that this is a very technically challenging area. Nonetheless, the BIOPROTA project was developed out of these recommendations, with the objective to support development of a consensus on how to address the issues, leading to the application of more coherent and consistent assessment methods.

The project benefited from a wide range of project partners with a range of technical information being provided as input to support the work of the project Technical Support Team (TST). The final project report is structured according to the following headings.

- Overview of Objectives and Derived Criteria for Human Health and Environmental Protection
  - Protection of people
  - Protection of the environment
- Review of:
  - Assessment Methods and Data Requirements for Non-radiological Assessments of Waste Disposal
  - Content and Application of Groundwater Protection Legislation as Applied to Waste Disposal Facilities
  - Design and Use of Toxicity Indices
  - Factors in Design of Effective Assessments
- Appendices:
  - Case studies of assessment of chemical alongside radiological impacts
  - Consideration of synergistic effects

The project considered both protection of people and the environment and included a review of assessment methods and data requirements. There was specific consideration given to the application of the EC Groundwater Daughter Directive. Consideration was also given to the design and use of toxicity indices that could be helpful in ascertaining what key hazard(s) to focus on. If assessments are to be coherent across all hazards then consistent criteria are required against which judgements can be made.

Key findings from the project are as follows.

- Non-radiological hazards of radioactive waste have been of increasing regulatory interest for a number of years but non-radioactive materials and possible impacts have been historically been under-characterised and under-researched.
- Superimposing a non-radiological performance assessment onto a radiological assessment, taking account of different compliance points and assessment criteria, different regulatory end points etc., can be and sometimes is done, *but it is difficult to fit into current regulatory frameworks.*
- The chemical hazard and/or risk is sometimes greater than that of the radioactive component.
- Hazardous waste environmental impacts arising post-disposal are not usually assessed over the long time scales required for radioactive waste.
- Given the above, ensuring an appropriate and proportionate level of environmental protection for both radiological and non-radiological components of the waste is hard to deliver and communicate.
- Radioactive and non-radioactive inventories in wastes, *waste packaging and the engineered facility* should be characterised quantitatively and with a proportionate degree of rigour, bearing in mind the amounts of material and intrinsic hazards.
- Release and transport of radionuclides and chemical contaminants from the engineered system, through the geosphere and in the biosphere, should be modelled by similar methods.
- This can be/is done for RW repositories. It helps that key non-radioactive contaminants often include metals and semi-metals.
- Evaluating the effects of exposures to mixtures of toxic agents and to determine potential for synergistic interactions is difficult. However, qualitative assessment is sometimes possible.
- For both exposure to ionising radiations and chemical pollutants, standards for environmental protection are generally based on precautionary approaches.
- However, they are not applied consistently, so that it is difficult to compare the effects of different environmental stressors or evaluate the overall impact of multiple stressors.

Case studies were identified that identify some priority chemicals that tend to be similar across different case studies. An annex was also developed on synergistic effects that aims to provide an evaluation of the current state of scientific knowledge relevant to this issue.

There are clear drivers to assess risks proportionately, but comprehensive assessment across all risks is impractical. However, if hazardous chemicals are considered it may be feasible to focus on the priority hazardous ones through the development of a hazard index that should cover not only the toxicity of substances, but also factors such as environmental mobility and solubility etc. Consistency could be further encouraged through parallel development of regulatory processes to provide a balance between prescription and guidance, allowing factors relevant to particular circumstances to be prioritised. A follow-up step should aim to support finding that balance. Furthermore, progress would be most effective if next steps were to focus on a limited set of hazardous components, especially for the relatively large volumes of LLW and VLLW arising in decommissioning of nuclear facilities and remediation of NORM and other legacy sites.

The project report has been published by the NRPA as SrålevernRapport 2018:6.

There are also several other related programmes that have been (and continue to be) active in this area. For example, similar issues were identified at a recent workshop hosted by NRPA, IAEA, NEA, ICRP and IUR on the regulatory supervision of legacy sites: the process from recognition to resolution (published as NRPA SrålevernRapport 2018:4). An NEA expert group on legacy management is also active in this area. A report on a practical and harmonised approach for the regulation of nuclear and radiological legacy sites is due to be published in June 2018. There may be merit in drawing together the different communities active in this area to share expertise and experience.

4.3 STUDIES ON C-14

Mike Thorne presented on behalf of the Technical Support Team for the BIOPROTA project.

A previous study, completed in 2017, identified some C-14 scenarios that could provide the basis for C-14 modelling studies within BIOPROTA. The scenarios relate to a forest ecosystem in Finland and Duke Swamp in Canada. The forest ecosystem scenario is based around C-14 transport through the forest canopy where isotopic anomalies in C-13 and C-14 have been measured. Duke Swamp is based around a series of studies of C-14 migration in groundwater from a waste management area to the swamp. These scenarios formed the basis for modelling work that has been undertaken in 2018. A review of the behaviour of C-14 in freshwater lakes and uptake into fish has also been undertaken.

The forest C-14 data arise from a boreal coniferous forest stand station (SMEAR II) that was established in 1995 in Hyytiälä, Southern Finland. The site includes a 128 m high tower for atmospheric and flux measurements, an 18 m tower for irradiation and flux measurements, another for tree physiology measurements and a 35 m walk-up tower for aerosol measurements. Carbon isotope ratios were measured between April and September 2012 and there is some evidence of a trend between $\Delta^{13}C$ and $\Delta^{14}C$ (‰) with a sinusoidal oscillation for both $\Delta^{13}C$ and $\Delta^{14}C$ being observed. This is a standard observation throughout the world for $\Delta^{13}C$. The $\Delta^{14}C$ signal is enhanced relative to $\Delta^{13}C$. No trend is observed in $\Delta^{13}C$ or $\Delta^{14}C$ with height through the canopy, but there are good isotopic signatures in the soil atmosphere, but no distinctions can be made between $\Delta^{13}C$ and $\Delta^{14}C$ values close to the ground surface or higher throughout the canopy. It is therefore apparent that CO_2 leaving the soil surface is rapidly diluted within the above-ground atmosphere (in the first metre above the surface). This is thought to arise because the volume of CO_2 leaving the soil surface is small compared with the volume of CO_2 carried through the lower part of the canopy by advection and turbulent diffusion. The lack of isotopic response in the experimental study implies that soil CO_2 never contributes more than 6% of total CO_2 in canopy air. A detailed model based on photosynthesis as a function of height and a simple flux-type model were applied to the forest scenario and results were a good fit to the observed data. The two models were based on similar physical principles and were concluded as being adequate for explaining the observations.

The Duke Swamp scenario considers a C-14 in groundwater plume from Waste Management Area C to the swamp. The area is characterised by complex hydrology. There is a clay lens and an aquifer below. C-14 has been measured in Sphagnum moss and in spruce throughout the swamp and an increase in C-14 activity concentrations in sphagnum has been observed as the groundwater plume enters the swamp. An initial single-layer model was applied, but was not sufficient. A two-layer model was therefore applied. The swamp is around 3 m deep with the majority of biological activity occurring in the top metre. As groundwater enters the swamp, the carbon entering the upper layer stops as it is retained by organic material. That entering the lower layer is able to continue into the swamp. Diffusion and dispersion occur between the two layers. The two layer model is illustrated in Figure 10. The two layer model estimated quite accurately the spatial distribution of C-14 within the swamp.

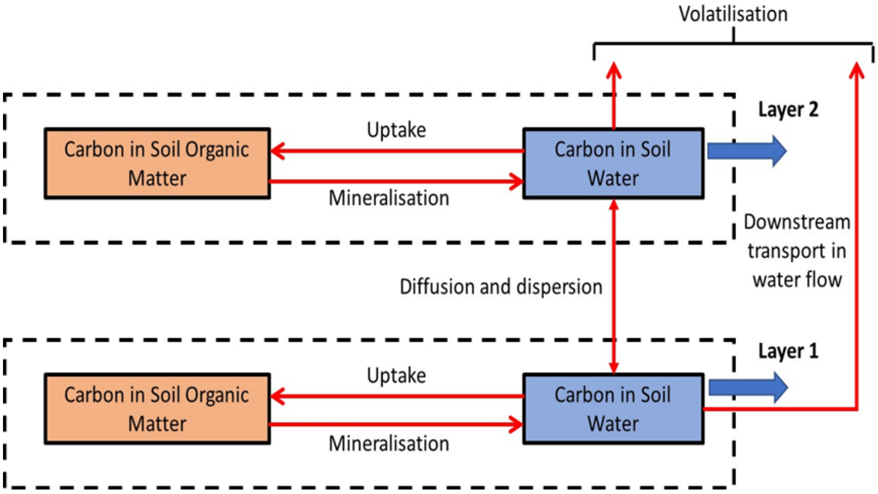

Figure 10. Two layer model for C-14 in Duke Swamp.

The modelling study of Duke Swamp emphasises that C-14 transport processes in systems based on organic soils can vary greatly due to spatial distinctions in turnover rates of organic matter and in the degree of water saturation present. Around 80% of the carbon entering the active layer is subject to volatilisation. Therefore, only around 20% is caught up in biomass production. In an organic swamp system, the degree of carbon uptake may be much higher than in a mineral soil.

An interesting observation for Duke Swamp is that about 20% of carbon released from organic matter by mineralisation is likely to be reincorporated in new biomass. This is a considerably larger percentage than would be expected for agricultural crops growing on mineral soils and likely probably reflects differences in the vertical distribution of primary productivity and in the degree of aeration of the soil.

A review of carbon behaviour in lakes identified terrestrial carbon as being a key contributor to the carbon cycle in lakes. Whilst both old and new terrestrial carbon can be incorporated into plant and animal lake biomass through primary production or direct consumption, the uptake rate for older carbon is lower, Where both lake-derived and terrestrial carbon are present, there appears a preference for within-lake carbon due to algal dissolved organic carbon being more energetically rich than its terrestrial counterpart. The role of methane as a source of carbon to aquatic food webs is also being increasingly recognised with isotopic evidence being available for the transfer of methane throughout aquatic food webs, as is the case for terrestrial systems.

The carbon uptake by fish review focussed on within-lake food webs, but uptake may vary for other systems such as rivers. There may therefore be merit in extending the review to rivers, with a view to identifying whether other uptake routes, such as via gills, could be important. There may be merit in developing, based on the review findings, a broader generic conceptual model for carbon pools and fluxes in lake (and river) systems and to consider timescales for turnover of the various carbon pools. It may also be useful to summarise modelling approaches that have variously been adopted and to compare these against the conceptual model for carbon in aquatic systems. Consideration could also be given as to whether published studies on stable isotope signatures in aquatic systems provide sufficient data to enable a model scenario based on carbon pools and fluxes between them to be developed as the basis for a model-model and/or model-data comparison study.

The draft report has been distributed to project sponsors for feedback prior to finalisation.

4.4 ANALYSIS OF C-14 IN BIOTA SAMPLES - METHOD DEVELOPMENT IN A MODELLING FRAMEWORK

Karin Aquilonius presented a planned study to be undertaken by SSM that may provide a useful data set for C-14 model validation. This follows from a presentation made during the 2017 annual BIOPROTA meeting of plans for a project to measure C-14 in aquatic samples, which has now secured funding.

There are several aims to the project:

- to increase knowledge of the behaviour of C-14 from nuclear power plants (NPP) in aquatic ecosystems;
- to contribute to the development of the national and international ability to analyse C-14 in biota samples using fast, accurate and cost-effective techniques; and,
- to produce a C-14 dataset from a Swedish marine ecosystem that could be used for the validation of models.

A key driver for the project is that C-14 is often a dominating contributor to dose assessments for members of the public.

The background to the project started in 2015 with a literature survey for analysis methods that could be used for C-14 in environmental samples that led to a methodology proposal. In 2016, the equipment was set up and the method tested and validated. A pilot study using bladderwrack samples from the coastal area around a Swedish NPP took place in 2017. Fourteen samples were collected and analysed. The method involves the combustion of samples, followed by the transfer of carbon to the liquid phase that can then be analysed in a low-background liquid scintillation counter. The measurements were validated against certified reference material and compared against measurements made using alternate techniques. Pilot study results indicate accumulation of C-14 in bladderwrack samples taken in a northward direction from the NPP. The observations match the circulation pattern for seawater in the area.

The objective now is to test the method in a larger study with samples being taken monthly throughout a year. Seawater, bladderwrack, mussels and fish will all be sampled and analysed for C-14. Water samples will also be subject to chemical and physical parameter analysis.

The analysis of C-14 in samples other than bladderwrack will require further method development and validation, which will be undertaken by a laboratory in northern Sweden. The method development and results of monitoring will be published in reports and as scientific papers. Depending upon the levels of interest among collaborators, modelling exercises may also be undertaken. It is intended that the project will begin in the summer of 2018 with analysis being completed by the end of 2019. Reporting and any modelling exercises would occur from 2019 onwards.

Discussion

The method will not allow old sources of C-14 in samples to be distinguished from recent NPP discharges and this should to be taken into account when looking at survey results. Furthermore, the water samples will not necessarily represent what macrophytes are seeing as a result of seawater mixing. These aspects should again be considered when interpreting the results of sample analysis.

4.5 IDEAS FOR POSSIBLE FUTURE COLLABORATIVE ACTIVITIES

An open discussion was held to invite suggestions for activities and projects that could form part of the future BIOPROTA work programme, including next steps for ongoing and recently completed work programmes. These are summarised in Table 4 below.

Table 4. Future collaborative activities and projects: summary of suggestions and discussions.

Task	Description and identified actions
BIOMASS enhancement continuation	A proposal for support in 2018 has been distributed inviting support from member organisations.
C-14 next steps	A dedicated C-14 workshop is proposed to take stock of where we are in terms of C-14 modelling and whether further collaborative work is helpful. The 2017 fish review was an initial stage and there may be merit in undertaking a more detailed review, encompassing also rivers. The biota monitoring data from SSM may also provide a useful data set upon which further tasks could be developed for the marine ecosystem. The holding of a workshop in 2018 could also help identify whether there are other aspects that SSM might consider including in the monitoring project that would support the development of a robust dataset for model validation activities. Some funding is already available and the TST will develop a proposal for a workshop and possible further aquatic system review.
Radioactive and hazardous waste assessments	There may be merit in further work on this topic. There are a number of related working groups and a BIOPROTA task to develop technical input to, for example, NEA or future IAEA MODARIA working group activities may be a useful next step. A proposal may be developed in light of NEA activities in this area. Alternatively, questions/suggestions from member organisations are invited. One suggestion is to focus on the limited number of substances identified in previous studies as being important hazardous substances and consider their interactions in the environment and the human body.
Topical workshop on biosphere modelling codes and correlations	The idea for a follow-on workshop to that held in 2005 on modelling codes was suggested prior to the annual meeting by Andra. The suggested workshop would focus on the model codes themselves with the aim of supporting decisions around the appropriate choice of model codes. The workshop would also aim to share experience on what has and has not worked in the application of different codes to biosphere assessments. The scope could also encompass how codes can be used to address uncertainties, including correlations. Complexity could also be touched upon. The output could include guidance on good practice. It was suggested that such a workshop could be held in 2019 / 2020.

Task	Description and identified actions
Topical workshop on special radionuclides	Recent developments in modelling the transport of some particularly interesting radionuclides was suggested as a topic for a workshop. This could provide the opportunity for discussion around particular issues in radionuclide modelling. For example, how to derive biota dose for radionuclides for which specific activity models are applied (e.g. Cl-36 and C-14) for which soil concentrations are required for the calculation of dose to biota.
Workshop / annual meeting session on lessons learned in licence applications and regulatory review	There has been a lot of experience gained in recent years by both operators and regulators on the licensing process, including license submissions and their regulatory review. A workshop focussing on lessons learned with regard to operator-regulator interactions and with the overall license applications could be beneficial for those at earlier stages in their waste disposal programmes. Such a workshop could also cover stakeholder engagement. It was suggested that this could form a topical session within an annual BIOPROTA meeting.
Post-closure monitoring	Post-closure monitoring was identified as a topic that will merit detailed discussion in the future. There is currently no guidance on post-closure monitoring and this may therefore merit a topical workshop / session during an annual BIOPROTA meetings.
Integrated modelling and biosphere dose conversion factors	There can be some surprises when moving from biosphere dose conversion factors to integrated assessment modelling and there may be merit in providing a forum for discussion, potentially as a topical session during an annual meeting, to allow sharing of experience. This should encompass differences in radionuclide treatment between unit release rate calculations as compared with time-dependent calculations in a changing landscape.
Application of biosphere models to decommissioning activities	There are challenges faced in the decommissioning of nuclear facilities and in remediation of legacy sites (such as increased discharges as key activities are undertaken). Sharing experience in biosphere assessments with others working in the fields of legacy site management and facility decommissioning could be an interesting topic for a topical workshop.
Site characterisation	Site characterisation was the topic of an initial BIOPROTA project with a report having been completed in 2006. With the experience gained by organisations in undertaking site characterisation since, there may be merit in revisiting this topic with a view to providing updated information and guidance around this subject.
Stakeholder engagement	Engagement with stakeholders can be challenging, particularly knowing when and how to engage with members of the affected public and other stakeholders. A topical workshop to share experience around this topic may be useful.
Groundwater compliance points and non-radioactive assessments	The issue of identifying appropriate compliance points in line with requirements within the EU Groundwater Daughter Directive was also raised as a potential workshop/session topic, drawing together experience on the application of the Directive's requirements in relation to radioactive waste disposal.

Task	Description and identified actions
Geosphere-biosphere interface next steps	A method for handling the geosphere-biosphere interface has been addressed in a recent BIOPROTA project, but there may be merit in further work focussing on the scientific handling of this interface within assessments. There is a call within a European Framework for Waste Repositories and this could provide a very useful opportunity to interact and identify needs that could give rise to new tools/solutions. Data needs could also be identified. A starting point would be to take stock of where we are in terms of the GBI from reviewing the past reports on this topic and considering what this means in terms of developing computational models.

Expressions of interest in the topics identified are invited. Proposals for projects/workshops to take forward the suggestions are also invited.

5. FORUM ARRANGEMENTS FOR 2018-19

Forum arrangements for 2018-19 are set out below, along with feedback from the 2018 Sponsoring Committee meeting.

5.1 FEEDBACK FROM THE SPONSORING COMMITTEE MEETING

Lauri Parviainen presented feedback from the 2018 BIOPROTA Sponsoring Committee meeting.

The topical session on monitoring had worked very well. It was suggested that similar sessions could be included in future annual meetings.

There is further interest amongst sponsors in tasks/workshops around monitoring programmes and linking biosphere assessment to the overall safety case. It was, however, noted that these could be topics addressed within the ongoing BIOMASS enhancement project. As such, it would be appropriate to revisit these suggestions following the completion of the MODARIA II programme, to identify whether topics have been addressed sufficiently or whether there would be merit in more detailed consideration.

The topic of new members to the forum was discussed at some length since there has been interest expressed by consultancies in membership. It was agreed that waste management organisations and regulators from different countries would be welcome as members, along with academic members, as agreed with sponsoring organisations. New members outwith these categories should be voted on by the current members. Potential new members could be invited to present on their interest areas during annual meetings to 'make a case' for their participation. A new grade of membership could be developed around this and an action was placed on the TS to consider this further and propose options to current member organisations.

5.2 FORUM ARRANGEMENTS IN 2018-19

Alexander Diener from BfS has kindly agreed to chair the forum in 2018-19 and to host the 2019 annual meeting in Munich. Subsequent to the meeting it has been confirmed that the 2019 annual meeting will take place in either the second or third week of May 2019 and members will be asked to confirm their preference in a poll.

A number of suggestions have been made for topical session topics to coincide with the BIOPROTA annual meetings. To allow sufficient time for presentations and discussion around these topics, thought could be given to extending the duration of the annual meetings (previously meetings took place over 2.5 days and a return to this may be worthwhile). Alternatively, a number of topical sessions could be grouped to form a topical workshop. Further suggestions and feedback are invited.

Finally, Lauri Parviainen was thanked for his work in chairing the forum in 2017-18 and for the hosting of the 2018 annual meeting.

APPENDIX A. 2018 MEETING PARTICIPANTS

Participant	Organisation	Country
Geert Biermans	FANC	Belgium
Maryna Surkova	FANC	Belgium
Jordi Vives i Batlle	SCK·CEN	Belgium
Neale Hunt	NWMO	Canada
Hana Hustakova	UJV/SURAO	Czech Republic
Ari Ikonen	EnviroCase (for SKB)	Finland
Ville Kangasniemi	EnviroCase (on behalf of SKB)	Finland
Lauri Parviainen	Posiva	Finland
Yves Thiry	Andra	France
Taku Tanaka	EdF	France
Rodolph Gilbin	IRSN	France
Alexander Diener	BfS	Germany
Tomomi Ito	Janus (part of JGC)	Japan
Yukiko Fukaya	Janus (part of JGC)	Japan
Sanae Shibutani	NUMO	Japan
Donghee Lee	KORAD	Korea
Jelena Popic	NRPA	Norway
Anders Wörman	KTH Royal Institute of Technology (on behalf of SSM)	Sweden
Olle Hjerne	SKB	Sweden
Peter Saetre	SKB	Sweden
Ulrik Kautsky	SKB	Sweden
Karin Aquilonius	SSM	Sweden
Maria Norden	SSM	Sweden
Shulan Xu	SSM	Sweden
Andreas Pöller	CSD (on behalf of NAGRA)	Switzerland
Jürgen Hansmann	ENSI	Switzerland
Ryk Klos	Aleksandria Sciences (on behalf of STUK)*	UK
Graham Smith	GMS Abingdon	UK
Alex Proverbio	LLWR	UK
Mike Thorne	Mike Thorne & Associates	UK
Russell Walke	Quintessa (BIOPROTA TS)	UK
Karen Smith	RadEcol Consulting (BIOPROTA TS)	UK
Ray Kowe	RWM	UK
Dawn Montgomery	Clemson University	USA

* STUK is not a member of BIOPROTA; its representative was given permission to participate in the meeting by Posiva.