BIOPROTA

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

Report of the Fifteenth BIOPROTA Workshop

Ljubljana, Slovenia
20-21 May 2013

Version 2.0
November 2013

PREFACE

This report was produced within the international collaboration project BIOPROTA.

BIOPROTA is an international collaboration forum which seeks to address key uncertainties in the assessment of radiation doses in the long term arising from release of radionuclides as a result of radioactive waste management practices. It is understood that there are radio-ecological and other data and information issues that are common to specific assessments required in many countries. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and to provide a transparent and traceable basis for the choices of parameter values, as well as for the wider interpretation of information used in assessments. A list of sponsors of BIOPROTA and other information is available at www.bioprota.org.

The general objectives of BIOPROTA are to make available the best sources of information to justify modelling assumptions made within radiological assessments of radioactive waste management. Particular emphasis is to be placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities. The programme of activities is driven by assessment needs identified from previous and on-going assessment projects. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions.

This report describes presentations and discussions held during the annual BIOPROTA workshop, hosted by ARAO in Ljubljana, Slovenia from 20-21 May 2013.

Version History

Version 1.0: Draft report prepared by Karen Smith and Graham Smith (BIOPROTA Technical Secretariat) and distributed 12 August 2013 to workshop participants for comment.

Version 2.0: Report prepared by Karen Smith and Graham Smith (BIOPROTA Technical Secretariat) accounting for participant comments on Version 1.0, and distributed 1 December 2013.

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1. INTRODUCTION

The fifteenth BIOPROTA workshop was hosted by ARAO in Ljubljana, Slovenia from 20 to 21 May 2013. The support of ARAO in the organisation and hosting of the workshop is gratefully acknowledged.

The objectives of the workshop were:

- to briefly update interested parties on progress since the last meeting in May 2012 on the various activities and projects supported through BIOPROTA;
- to provide an informal forum for continuing exchange of information and discussion about biosphere topics of interest; and
- to identify common scientific issues relating to the assessment and analysis of safety for radioactive waste disposal facilities, upon which collaborative tasks may be developed.

The workshop was opened by ARAO with a welcome and short overview of the current status of the waste disposal programme in Slovenia. The siting process for a disposal facility in Slovenia began in 2004 and, in 2009, a site was selected. Since this time, the focus within ARAO has moved to optimising the design, and considering both how the facility will be constructed and operated. Consequently, a key focus of the programme is on demonstrating safety and public confidence. The sharing of knowledge, experience and ideas with other organisations, through meetings such as BIOPROTA, is an important aspect with regard to being able to demonstrate that the disposal concept is safe, is in keeping with international practise and is up-to-date with the latest technology.

This was followed by an introduction to the workshop from Ray Kowe (NDA-RWMD), the current BIOPROTA Sponsoring Committee (SC) chairman. Sandi Viršek and colleagues from ARAO were thanked for their role in organising and hosting the workshop. Simon Norris (NDA-RWMD) was also thanked for his role as co-chairman of the forum in 2012. FANC, the Belgian nuclear regulatory authority, was welcomed as a new member to the forum in 2013. Current membership is thus:

- Andra, France
- ARAO, Slovenia
- AREVA, France
- BfS, Germany
- CIEMAT, Spain
- EdF, France
- EPRI, USA
- ENSI, Switzerland
- FANC, Belgium
- IRSN, France
- JGC Corporation, Japan
- KAERI, Korea
- LLWR, UK
- Nagra, Switzerland
- NDA (RWMD), UK
- NRPA, Norway
- NUMO, Japan
- NWMO, Canada
- Posiva, Finland
- SCK.CEN, Belgium
- SKB, Sweden
- SSM, Sweden

- UMB, Norway (academic member)
- OSU, USA (academic member)

BIOPROTA therefore consists of a range of stakeholders with an interest in solid radioactive waste disposal and associated long-term biosphere assessments. However, there are broader scientific and assessment issues that are related (e.g. uranium-mining legacy sites, NORM and contaminated land) and the remit is therefore not restricted to disposal of long-lived radioactive waste. The objective of the annual meetings is to identify relevant assessment issues upon which projects, focussed workshops and bi-/multi-lateral initiatives can be developed. Mr Kowe reiterated the message from ARAO that the meetings provide the opportunity for the sharing of knowledge and experience that can assist in validation of the programmes undertaken by different organisations. Ultimately the forum meetings provide an informal test bed for new ideas and participants are encouraged to identify critical issues for which resources can be shared to address these issues through the establishment of focussed work programmes.

Reports produced as a result of BIOPROTA work since the last annual meeting in May 2012 include:

- 2012 Annual Workshop Report (Nancy)
- Se-79 in the Soil-Plant System, June 2012
- Dose Assessments for U-238 Series Radionuclides, August 2012
- Human Intrusion, Sept 2012

A number of work programmes are also on-going and new ideas for projects have been raised, see below for further details. BIOPROTA work programmes are not intended to proceed in isolation; rather, links with other working groups, such as those within MODARIA, STAR and CERAD are encouraged. Dissemination of project output is also encouraged through conference and other meeting presentations as well as peer-reviewed publications in relevant scientific journals.

1.1 WORKSHOP PARTICIPATION

The workshop was attended by 35 participants, representing a range of operators, national regulatory authorities, technical support organisations and academic researchers, as listed in Appendix A.

1.2 REPORT STRUCTURE

The remainder of this report is structured to provide:

- An overview of progress made in 2012/13 (Section 2);
- A summary of presentations made by participants on their biosphere programmes, including challenges faced (Section 3);
- An overview of other relevant working groups and programmes (Section 4);
- A summary of interest areas that could form the forward programme and forum administrative issues (Section 5).

2. PROGRESS IN 2012/13 OF ESTABLISHED BIOPROTA WORK PROGRAMMES

2.1 MODELLING APPROACHES TO C-14 IN SOIL-PLANT SYSTEMS AND AQUATIC ENVIRONMENTS

Graham Smith presented.

Three previous working reports have been produced as a result of BIOPROTA work programmes on C-14 that have helped improve understanding of the processes that need to be considered in models. However, issues still remain around model parameterisation, temporal and spatial averaging, and processes such as the oxidation of methane to form $^{14}CO_2$ with subsequent uptake into plants.

A summary of the work done to date and plans within the current C-14 project were presented at a Radiocarbon conference in the summer of 2012 and a publication has been accepted for publication in the conference proceedings.

Since these publications, further information has been made available as a result of new initiatives and work programmes, such as those undertaken by NDA-RWMD and LLWR that are aimed at reducing uncertainties in models. The current project therefore aimed to review this new information, but also considered, in addition to the terrestrial system that has been the focus of projects undertaken within BIOPROTA to date, the aquatic system in terms of relevant processes and models based on a review of readily available information. This information was collated and presented during a workshop hosted by SKB in Stockholm in February and presentations and discussions have been summarised in a workshop report. A final draft of that report has been made available to project sponsors for approval to publish. An addendum to the workshop report is also planned to take account of further on-going work by member organisations that is due to be published in the autumn.

As a result of the workshop, various options have been identified for the next steps of work on C-14, including:

- The application of recently developed soil-plant models to well-defined cases and comparison of results against each other and against results obtained in the previous BIOPROTA model inter-comparisons.
- Testing of models against field data, potentially from a site near to the AREVA facilities at Cap de la Hague, from freshwater discharges from nuclear power plants, and RWMD sponsored research being undertaken at the University of Nottingham.
- Identification of models for C-14 transport in aquatic systems and relevant monitoring data to allow model evaluation and testing and, for wetlands, make use extensive hydrological and C-14 datasets that are potentially available for Duke Swamp.
- Determine general conceptual model structures appropriate to C-14 transport in different ecological contexts. This could then form a basis for evaluating the temporal and spatial scales over which assessments should be undertaken for both humans and non-human biota.

Further information on next steps is provided in section 5.

2.2 THE GEOSPHERE-BIOSPHERE INTERFACE PROJECT

Mike Thorne presented.

There are numerous types of interface between the geosphere and biosphere, but well water extraction and groundwater discharge are two primary types considered in long-term safety assessments for the geological disposal of radioactive waste. These have thus been selected as the basis for the development and test application of a methodology for evaluating the transfer of radionuclides across the geosphere-biosphere systems (GBS). In the past, the approach was often to consider just one biosphere that could be ‘bolted’ on to any geosphere system, but realisation has grown that this is not appropriate. The project therefore aims to move on by considering what has been done within safety assessments to date, and to consider a method for identifying geosphere-biosphere systems and establishing relevant conceptual models and their mathematical representation. The project has established close links with working group 6 of MODARIA.

An initial project workshop was hosted by RWMD in London in March 2013 at which approaches taken by different organisations to representing the GBS were presented alongside a comprehensive briefing note which sets out a proposed a structured methodological approach to representation of the GBS, A sub-set of the range of specific GBSs was agreed for further consideration throughout the remainder of the project. These sub-systems provide the assessment context, required as a starting point in evaluating relevant components of the GBS. A report of the workshop has been produced and distributed to workshop participants for comment and further work has progressed to fully describe those sub-systems and to further develop and test the methodological approach. Each sub-system will be used as the basis for studying in detail the characteristic features, the events that could perturb them and the processes determining both their evolution and the transport of radionuclides within them and across their boundaries.

Whether or not climate change is required to be considered very much affects the level of consideration given to the GBS. A flow chart has been developed that assists in identifying the relevant GBS states and transitions between them. These can then be characterised at the appropriate scale (e.g. climate mapping from global to regional scales is required) to identify relevant states and associated transitions. Considerations include landform, hydrological flow regimes and the effects of perturbations such as the sinking of wells. Interaction matrices will be used to identify and represent relationships between different components of the system and the processes that are relevant to those interactions. As the conceptual model develops, for example in moving from generic to site-specific considerations, the interactions between components of the system will become more specific and descriptive. Within the project it is aimed to balance the level of complexity presented to ensure the information is useful and applicable to other assessment contexts.

A structured assessment method has been proposed for developing conceptual models of the GBS and has, to date, been tested through application to a Lowland Britain scenario that was the focus of past-work by Nirex/RWMD. The method will also be applied to the Swedish Forsmark site and central Spain. It is intended that the method will be modified as the project continues.

The results of the application of the method to the three test-cases will be presented in a second briefing note that will be distributed prior to a further project workshop to be hosted by ANDRA in Paris toward the autumn. Mathematical models available to represent the different components of the conceptual models will subsequently be considered.

2.3 SCALES FOR POST-CLOSURE ASSESSMENT SCENARIOS (SPACE)

Karen Smith presented.

IAEA guidance on safety cases for solid radioactive waste disposal given in SSG-23 is clear that regulatory criteria will be established by the regulatory body and, as a minimum, need to address radiation dose and risk constraints for workers and the public (both present and future generations), and protection of the environment. However no guidance is provided on how to address protection of the environment in this context. Indeed, it is noted that, "An international consensus on approaches and criteria for addressing this issue is still evolving.".

ICRP publication 108 sets out the aim for environmental protection as being, "To prevent or reduce the frequency of deleterious radiation effects in the environment to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities and ecosystems". This, taken with similar discussion material, suggests that whilst the human protection goal is largely recognised as individual based, the goal for plants and animals is protection of a population of a relevant species.

Relative to human dose assessment, biota assessments are at early stage of development. The focus has been on dosimetry tools and supporting data bases. Little attention has been given to date to the spatial scales appropriate to assessments for populations, although they are increasingly acknowledged as important considerations. In the case of underground waste disposal facilities, the question is how to appropriately justify the assumptions for averaging contaminant concentrations arising from releases through the geosphere-biosphere interface (GBI) that seen by the biotic populations of interest, While the dosimetric basis for turning an environmental concentration into a dose rate for comparison with various proposed dose rate standards is relatively clear, it is not so clear how to calculate the relevant concentration. For example, some animal may range over a much larger area than that most significantly contaminated by releases across the GBI, while others with a small range do not; however, the population of interest of the latter may exist over a much wider area. The issues are illustrated in Figure 2.1. Temporal averaging may also be important, especially if changes in environmental concentrations and the movement of the population of interest are on different timescales. It may be that averaging assumed for human protection provides adequate safety assurance, but this may not always be the case.

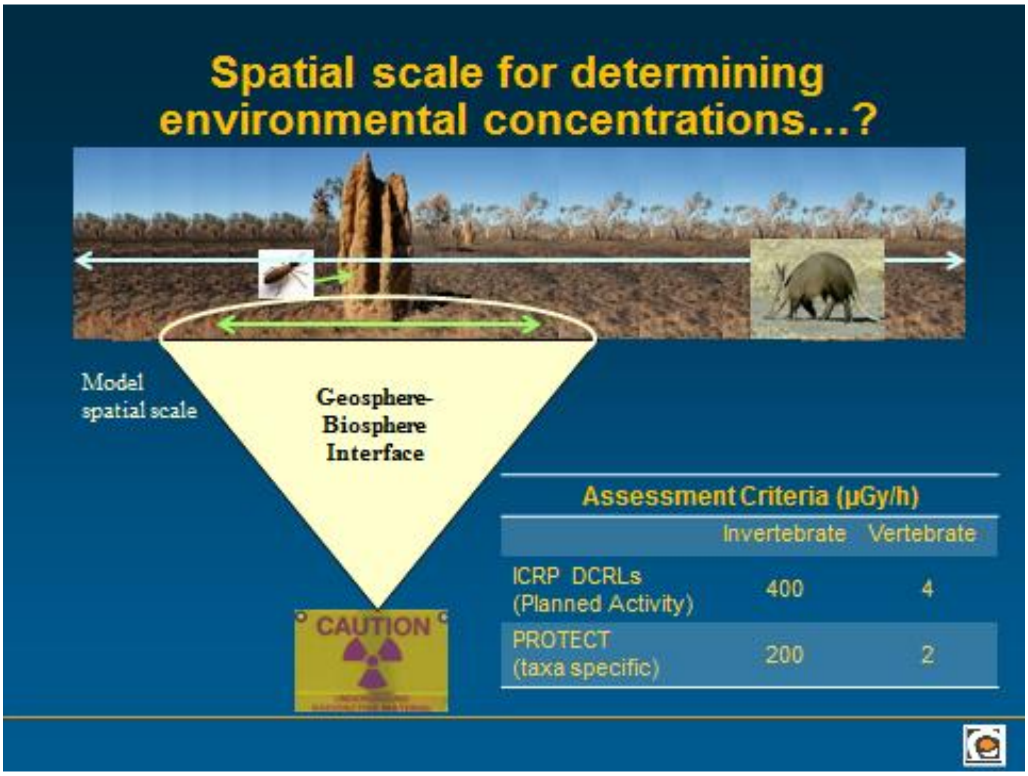


Figure 2-1. Illustration of spatial scaling issues for different biota

To give some further consideration to these issues, the SPACE project has been set up within BIOPROTA. The specific objective is to check that spatial and temporal averaging adopted for determination of environmental concentrations for human protection are appropriate for demonstration of protection of the environment and, if not, to determine the appropriate temporal and spatial scales. Tasks include:

- Review of rationale for addressing spatial and temporal scales within human and NHB dose assessments. [completed]
- Identification of relevant spatial and temporal scales for humans, recognising temporal variability in human utilisation of ecosystems and their resources. [completed]
- Identify relevant scales for wildlife populations represented by 'reference organisms' used within many of the wildlife dose assessment models [species list distributed for comment].
- Evaluate commensurability between human scales and the newly defined 'reference groups' defined on basis of similarities in scales for representative species.
- Identify modelling requirements to address scale issues in post-closure NHB dose assessments and develop a methodology document which presents the strategy for undertaking 'reference group' assessments.
- Demonstrate the application of this methodology to a specific case study.

It is planned to hold a workshop to discuss the draft results in late 2013 or early 2014, and to provide sponsors of the project with a complete draft report by March 2014.

2.4 WORKSHOP ON THE SCIENTIFIC BASIS FOR LONG-TERM RADIOLOGICAL AND HAZARDOUS WASTE DISPOSAL ASSESSMENTS

A variety of environmental impact and human health assessments is used to support decisions on the management and disposal of radioactive and hazardous waste. These assessments have to address a wide range of protection objectives, ecosystems and timeframes. This creates significant challenges to the design of such assessments and in the development of corresponding relevant scientific support. Accordingly, a workshop has been arranged to provide a forum for discussion and comparison of the scientific basis for such assessments, taking into account:

- assessment methodologies for disposal of radioactive and other hazardous waste;
- assessment endpoints (quantities assessed as a measure of environmental and/or human health impact);
- the key processes which dominate the release and disposition of radionuclides and other pernicious pollutants within the environment, following disposal;
- timeframes for assessment and approaches to dealing with environmental change;
- methods for assessing effects on human health and the environment;
- assumptions for human behaviour and land use, and how that affects the potential for impacts both on human health and on the environment;
- approaches to addressing uncertainties, and
- approaches to addressing low probability events which have high consequences.

Through the sharing of experience on the above topics, it is intended to develop ideas for complementary, consistent appropriate scientific support for in different assessment contexts. With the kind support of ARAO and GEN energija d.o.o., the workshop has been organised to take place in Ljubljana from 22 – 24 May 2013. A workshop report will prepared in due course.

3. PROGRESS IN MEMBER ORGANISATION BIOSPHERE PROGRAMMES

The following sections provide an overview of the programmatic update presentations provided by the various participants from member organisations.

3.1 UPDATE ON SKB PROGRAMME AND AMBIO

Ulrik Kautsky presented.

The SKB SR-Site license submission for the construction of the HLW disposal facility at Forsmark was made in 2011 and is currently under review and on-going work at SKB is therefore focussed on addressing questions and comments arising as a result of the review process. In addition, work is progressing on the license submission for the extension to the disposal facility for short-lived waste (SFR) and the assessment completed in 1998/99 for the SFL facility for intermediate long-lived waste is being revisited in terms of the disposal concept. No site has yet been selected for SFL; it may be co-located with SFR and the facility for spent nuclear fuel (SR-Site) or an entirely separate site may be selected. Much of the waste intended for disposal in the SFL facility will be that arising from decommissioning activities plus some industrial and research waste that was generated in the 1960's.

The last 3 years of biosphere research and development work has resulted in some 40 reports and 30 scientific papers. The research and development programme for the next 3 years will be focussed on addressing review comments and exploring in more depth the database that has been developed as a result of extensive site investigation work. Much of this data is available within the different reports published by SKB. In addition, the SFL programme will continue and work will progress on the next generation of assessment models, with the potential to move from PANDORA to alternative models such as ECOLEGO. The research programme must be developed in line with budget constraints and changes associated with new management and controllers. It is intended that the draft research and development programme for the next 3 years will be finalised and submitted to regulators in September.

A special issue of the journal AMBIO (volume 42 (4)) has recently been published which focusses on the work undertaken by SKB on their license submission for SR-Site. The publication, which is open access[a], is entitled 'Humans and ecosystems over the coming millennia – a biosphere assessment of radioactive waste disposal in Sweden'. More than 40 individuals have contributed to the special issue, which provides an overview of the research programme and separate papers on the different foci of the biosphere assessment. These include (among others) hydrology, climate, oceanography and land development, human diet assumptions and radionuclide transport. A biota assessment is also reported whereby site-data have been applied to calculate doses to ERICA reference organisms.

Feedback on the issue is invited. An open seminar is planned toward the end of September.

3.2 THE UK HIGH ACTIVITY WASTE DISPOSAL PROGRAMME

Ray Kowe presented.

[a] http://link.springer.com/journal/13280/42/4/page/1

The Nuclear Decommissioning Authority (NDA) is a non-departmental public body created through the Energy Act 2004 and has assumed responsibility for the sites previously owned by British Nuclear Fuels plc (BNFL) and United Kingdom Atomic Energy Authority (UKAEA).

The NDA owns 19 sites, built in the post-war days of the UK's early nuclear programme, which now need to be cleaned up and restored (Figure 3-1). The NDA is responsible for implementing Government policy on the long-term management of nuclear waste. It also has a role to scrutinise the decommissioning plans of EdF nuclear power stations in the UK (formerly British Energy).

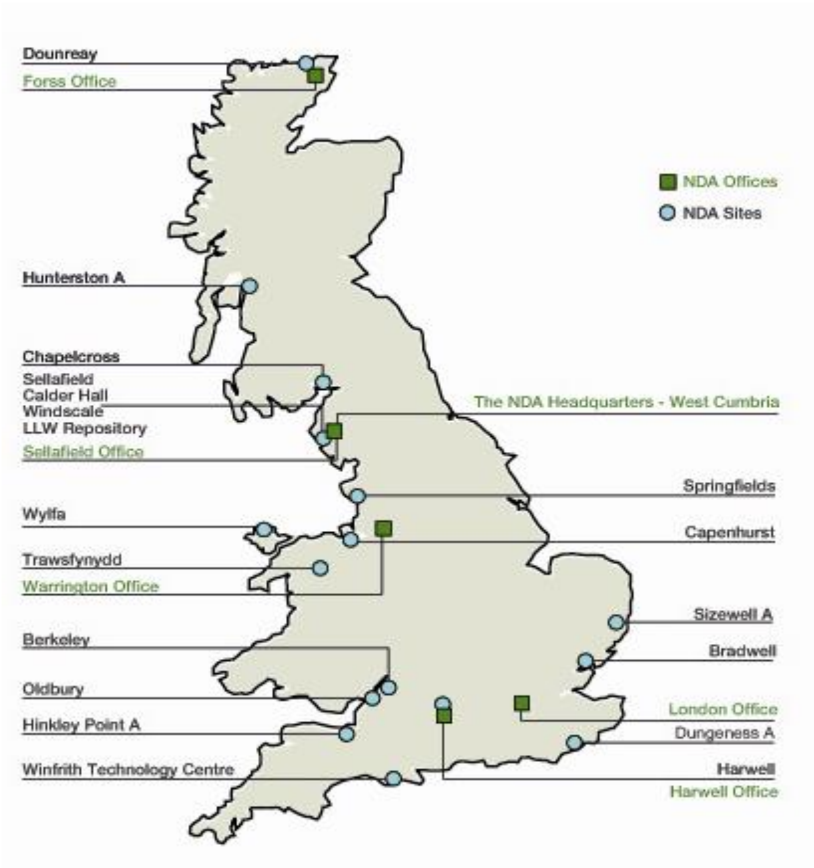


Figure 3-1. NDA sites (figure published with permission of the NDA).

Radioactive waste in many different forms is present at all of our sites and we have been given UK wide responsibilities for some important aspects of waste management that extend beyond our estate including assets and materials on our sites that are currently owned by other organisations and for which they have ultimate responsibility. It includes MOD submarine propulsion fuel which is stored at Sellafield under contract and Advanced Gas-cooled Reactor (AGR) fuel belonging to EdF and not contracted for reprocessing.

Higher activity waste includes:

- Low Level Waste (LLW) - overall, the major components of LLW are building rubble, soil and steel items from the dismantling and demolition of nuclear reactors and other nuclear facilities. About 93% of the UK's radioactive waste by volume is LLW, but it contains less than 0.01% of the total radioactivity. Most LLW is sent to the Low Level Waste Repository near Drigg in Cumbria or in certain cases to specific landfill sites soon after it is produced.

- Intermediate Level Waste (ILW) - ILW comprises of metal items such as nuclear fuel casing and nuclear reactor components, graphite from reactor cores, and resins from the treatment of radioactive liquid effluents. About 7% of the UK's radioactive waste by volume is in the ILW category, which represents about 5% of total radioactivity. For most ILW, packaging consists of immobilisation in cement-based materials within 500 litre stainless steel drums.

- High Level Waste (HLW) – these are wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of waste storage or disposal facilities. Initially HLW comprises nitric acid solutions containing the waste products of reprocessing spent nuclear fuels. Although less than 0.1% of the UK's radioactive waste by volume is HLW, it contains about 95% of all radioactivity. The highly active waste is turned into a solid glass form (vitrified) and encased in a stainless steel canister.

An integrated approach to the way in which these wastes are treated, packaged, stored and disposed is vital to ensuring long-term safety, security, protection of the environment and value for money to the taxpayer. Effective waste management is essential to delivering our decommissioning programme. The NDA also manages other radioactive materials – Spent Fuel, Plutonium and Uranium – but these are not yet categorised as waste.

In 2003, the UK Government set up the Committee on Radioactive Waste Management (CoRWM) to consider the question of how higher activity waste will be managed in the long-term. In July 2006, CoRWM recommended geological disposal as the best available solution, with safe and secure interim storage in the meantime, and ongoing research and development to support its optimised implementation. This is the internationally preferred approach, being taken forward by countries including Finland, France, Sweden and the USA.

Government adopted CoRWM's recommendation that the solution for the long-term management of the UK's higher activity radioactive waste is geological disposal, with the NDA being responsible for its implementation. In 2008 the Managing Radioactive Waste Safely (MRWS) White Paper was published which outlined the framework for implementing geological disposal and set out Government's preferred approach to site-selection based on the principles of voluntarism and partnership. The NDA have defined a number of phases in our programme of work for successful implementation of a geological disposal facility that run from its initial planning through to its closure and beyond, with the earlier phases being aligned to the stages of the site selection process set out in the White Paper.

Three local authorities formally expressed an interest in the MRWS programme: Copeland and Allerdale Borough Councils, and Cumbria County Council. In January 2013, the three local authorities voted on whether to proceed to Stage 4 of the process. The two boroughs voted in favour, but the county voted against. The Government had in 2011 given a specific undertaking that the existing site selection process would only continue in west Cumbria if there was agreement at both borough and county level. The county's decision therefore ended the existing site selection process in west

Cumbria. Shepway District Council in Kent had also taken soundings from local residents, but subsequently decided against making a formal expression of interest in the MRWS process.

The Government remains committed to geological disposal as the right policy for the long-term safe and secure management of higher-activity radioactive waste, and that the best means of selecting a site for a geological disposal facility is an approach based on voluntarism and partnership. Government has been considering what lessons can be learned from the experiences of the MRWS programme in west Cumbria and elsewhere and has invited views ("Call for Evidence") on the site-selection aspects of the on-going MRWS programme as the next stage in that process. The responses to this Call for Evidence will inform a public consultation that will follow in the autumn.

3.3 UPDATE ON THE SLOVENIAN L/ILW REPOSITORY PROJECT

Sandi Viršek presented.

ARAO was established in 1991 and is the state-owned radioactive waste management agency of Slovenia. The organisation is financed through a decommissioning fund, state budget and contributions from small producers and others. Within ARAO there are 5 people working on the L/ILW repository project.

Nuclear waste in Slovenia arises from a nuclear power plant that is half owned by Croatia, and a closed uranium mine and a research reactor. A small interim storage facility is located near the capital and there is closed uranium mine and a research reactor.

Spent fuel and HLW are currently stored in ponds that were planned to remain operational until 2050 with dry storage following. However, following the Fukushima accident it is now envisaged that dry storage will move forward, possibly to 2017, which represents a large scale project. The final solution for spent fuel and HLW has not yet been decided. Some screening has been done on the geological conditions throughout the country, indicating that a few areas may be suitable, but much of the country is not. There is however no siting process established at the current time.

For institutional L/ILW, arising from research, industry and medicinal applications, there is an interim storage facility at Brinje. The current stored inventory is some 85 m^3 of radioactive waste. However, the final disposal solution needs to take into account final volume of waste that will arise, including from the nuclear power plant, for which there is a large uncertainty (range ~4,000 to 18,000 m^3).

The repository siting process for L/ILW began in 2004. There were 3 initial communities and, in 2009 the siting process was completed successfully with the Vrbina – Krško site being selected and subsequently approved by government. However, there are on-going discussions as to whether this is the best site or whether others would be preferable if public acceptance could be achieved. Nonetheless, work is on-going to demonstrate that disposal can be safely achieved and to improve public confidence. Three conceptual designs have been considered: surface concept on embankment (dam); near-surface concept (silos excavated from the surface); and underground concept (underground galleries with access through shaft or ramp). The near-surface concept is preferred and a strategic environmental impact assessment for the Vrbina – Krško site indicated that this concept is safe (dose results are substantially below safety constraints). In 2009, the Slovenian Government approved the near surface disposal concept and the Vrbina – Krško site.

The initial disposal concept involves silos constructed to a depth of 55 m with a drainage gallery at the base with disposal of waste containers (10 layers of 70 containers) being by surface crane. Shotcrete in three layers of around 50 cm will be used in the initial construction. Concrete and clay layers will be used for the final closure of the facility. Whilst two disposal silos are planned to take all waste that could arise in Slovenia, Croatia has not yet declared how they will dispose of their half of the waste from the shared nuclear power plant.

There are some issues with the site for which optimisation studies are being undertaken. The site is located near to a river which means it is subject to periodic flooding (at intervals of around 4,000 years). An embankment will therefore be constructed to protect against possible floods, the height of which will be calculated for the probable maximum flood height at site.

Site investigations have also indicated that the groundwater table is high and groundwater flow is often in an upward gradient. However, whilst this is not ideal, the safety assessment has indicated that safety criteria can nevertheless be met. Since the silo will be saturated by groundwater after closure, the processes and rate of saturation are uncertain which leads to uncertainties in the safety assessment. As such, the facility may be artificially saturated prior to closure which would simplify the assessment. Due to the hydrological conditions, pre-fabricated elements may be required for the liner during construction to avoid hydraulic pressure issues.

Clay is being used in the silo cap to prevent aquifer infiltration. The aquifer is located above the top of the silo at around 5 m depth. Since there are vertical gradients to groundwater flow in the area, the use of clay will help to prevent upward flow issues. An alternative approach could be the construction of a hydraulic cage.

Whilst a drainage system below the silo is useful during the operational phase, the pressure variation following closure could force water and associated radionuclides into the drainage system. The drainage system may therefore be excluded from the final design.

Consideration is also being given as to the optimum design of waste containers. Waste is currently stored in drums and repackaging is not a preferred option, hence concrete containers are being considered that would take multiple drums. However these containers would be of large dimension (around 2.5 m by 2.5 m by more than 3 m high) and are thus heavy. The large dimensions arise from a need to increase storage at the nuclear power plant where storage is limited to two layers, but the facility is almost at capacity due to storage being in drums. Use of large concrete containers would alleviate the issue of two layers by allowing multiple drums to be included in one container and are therefore being considered. If such large containers are employed there could be an issue around a drop scenario when containers are emplaced within the silos. The use of a single-failure crane is being considered to avoid this issue. Waste packages from the nuclear power plant would have to be monitored to ensure they meet waste acceptance criteria.

Additional challenges faced include ground excavation and silo construction. For example, it is not known for certain how the facility will behave once empty due to buoyancy forces. Research is also required on concrete durability and whether construction of the silo should be in one piece or multiple: issues around the ability to construct the facility have been raised by the IAEA and work is therefore required to demonstrate the concept.

In terms of gas generation, two scenarios are being considered. One involves blow out following gas build-up and the other diffusion through cracks. Both scenarios are the subject of investigation and optimisation (such as the installation of valves to prevent over-pressure).

Work on optimisation of the final design of the facility and waste containers therefore continues with the objective of obtaining a license to construct in 2016, with construction being completed by 2019. A nominal construction cost of 147 million Euros is anticipated.

Since there is presently only a small amount of waste compared to the total that will be disposed, an idle phase is planned during the operational period whereby disposal will be paused and the facility maintained prior to the decommissioning of the nuclear power plant with disposal then recommencing around 2050.

3.4 U.S. EPA CERCLA (SUPERFUND) REMEDIAL PROGRAM'S APPROACH FOR ECOLOGICAL RADIATION RISK ASSESSMENTS FOR BIOTA RECEPTORS

Stuart walker presented.

The US EPA SUPERFUND programme takes on the remediation of legacy contaminated sites. Contamination can be from radioactivity and/or chemicals. At the current time, there are 1304 registered national priority listed (NPL) sites. Of these, only 66 are contaminated with radioactivity. There are, in addition, around 60 sites proposed as NPL, of which 1 is radioactively contaminated. The radioactively contaminated sites include abandoned uranium mines, thorium gas mantle sites and large Department of Energy sites such as the Hanford site. Whilst classed as radioactively contaminated, chemical contamination is almost always present. The remediation costs for the radioactively contaminated sites are often very expensive: for example the Hanford site clean-up costs are expected to be around $40-50 billion. Clean up decisions are made site specifically; regional offices make decisions out in field, but these decisions must comply with law (CERCLA - Comprehensive Environmental Response, Compensation & Liability Act) and (NCP - National Contingency Plan) so there is some consistency between sites. Due to the remoteness of many of the sites, on-site disposal facilities are often required as part of the remediation activities. The need for disposal facilities on a site is often the cause for the differences in cost between chemically and radioactively contaminated sites.

Altogether there are nine remedy selection criteria for SUPERFUND sites, two of which are threshold criteria that must be met:

- protect human health and environment.
- Comply (attain or waive) with other federal and state laws, including the protection of current or future sources of drinking water.

There are then five balancing criteria that are used to evaluate between different remedy options that meet the threshold criteria. The balancing criteria, which are largely qualitative, are:

- Long-term effectiveness and permanence;
- Reduction of waste toxicity, mobility, or volume;

- Short-term effectiveness;
- Implementability; and
- Cost.

Finally, there are two modifying criteria (state acceptance and community acceptance) that allow public opinion to modify remedial actions.

Historically the approach was to ensure protection of the people, and sometimes it was then inferred that ecological protection would also be afforded. Until around 1995 only some 20% of Superfund sites were cleaned to an restricted release level, since then it is probably closer to some 20% being cleaned to unrestricted release. EPA has found that the sites cleaned up to restricted land uses for humans are not necessarily protective of the environment. More recently however there has been a move towards more quantitative ecological risk assessment (ERA) and risk management principles with guidance being provided on the development of benchmarks for ERA. Based on requirements in the NCP, "adequate" protection should be afforded to ecological receptors from "unacceptable" risks.

A new ecological risk assessment calculator is currently under development and will be made available for use online later in the year. The calculator will be used to establish risk-based Biota Concentration guides (BCGs), or ecological benchmarks, for radioactively contaminated sites. The dose criteria for biota are based on the DoE graded guideline approach, which stipulates 1 rad/day for plants and aquatic/riparian animals and 0.1 rad/day for terrestrial animals. Both generic and site-specific models will be included, but there will be only limited ability to include site data since the initial models will be used for screening purposes. If the environmental concentrations are below the calculated concentration guides then no further assessment will be required. However, if above then the next step would be to apply kinetic/allometric equations, incorporating site specific species and data to generate species/site specific benchmarks. When selecting representative species for species specific benchmarks the following should be considered;

- Preference given to organisms with small home ranges;
- Organism should be susceptible to ionising radiation;
- Organism should represent major exposure pathways;
- Organism should be indigenous to the area;
- Organism should have a reasonable amount of data published and available; and,
- Organism should be appropriate for the community being evaluated.

Dose conversion factors (DCF) are currently being used by the US DoE for 42 radionuclides, but this is being expanded to take account of other relevant radionuclides. The DCF's will vary according to the size of the animal, and animal sizes in the calculation tool will range from approximately the size of a vole to a moose.

There are a number of issues that are commonly faced at sites when undertaking ecological dose calculations. In particular, dose limits for biota are often higher than for people due to the focus of protection being on populations rather than individuals. Nonetheless this needs to be communicated to the public. The species considered are also not necessarily ones of particular public interest, hence both cat and dog are being added to the calculation tool. Regular meetings are held with regional offices in order to discuss lessons learned from application of the ecological assessment approach to sites in order to develop a comprehensive ERA method. From this, a number of research needs have been identified. These include the need to develop dose limits for a wider range of animal groupings such as herbivores, carnivores and both pelagic and benthic fish in order to take account of factors affecting exposure (routes of intake and external exposure). Greater consideration of the sorption of radionuclides in the environment also requires consideration in terms of what this means for the exposure of plants and animals. Consideration is also being given to the need to combine assessment approaches for chemicals and radionuclides where these are both present at NPL sites and to include multi-stressor effects in terms of additive, synergistic and antagonistic responses to pollutants.

3.5 CURRENT STATUS OF THE BIOSPHERE ASSESSMENT PROGRAMME AT NUMO

Takao Ohi presented.

The biosphere assessment concept is to demonstrate safety of a geological disposal facility and the assessment must be representative in terms of long term environmental change, including topographic changes. Confidence in the assessment must be as high as possible and this must be demonstrable to stakeholders around a candidate site.

The strategy for biosphere assessment is to define common features in each phase of the programme, such as preliminary and detailed site investigations and up to date data must be employed. Similarly, new models should be adopted as developed by research organisations (e.g. JAEA) and recommendations taken into account as a result of research programmes such as BIOPROTA. High priority research areas must be identified for investigation.

Candidate disposal sites have not yet been identified so the programme is in the preliminary stages and is generic. Biosphere assessment is therefore based on stylised models for the type of sites that could be suitable for disposal throughout Japan.

In support of biosphere assessments, a manual for data acquisition, to support the site-specific assessment, is being prepared. The manual has seven focus areas:

- Strategy for data acquisition and selection in post preliminary investigation phase;
- Identification of a biosphere assessment model in which the significance of the target parameters is clear;
- Current status of data acquisition and selection;
- Information on data acquisition and selection in another technical field;
- Method for data acquisition and selection in post preliminary investigation phase;
- Estimated cost; and

- Schedule and identification of future issues.

The parameters included within the manual were derived on the basis of sensitivity analyses from several biosphere models. Parameters are divided into two types: one comprises migration related parameters and other exposure pathway model parameters. The source of data for each parameter is defined according to whether the data are to be sourced primarily from literature sources with supporting arguments, from site investigations or whether data are to be obtained from models developed and applied for data selection, taking into account site properties. Data statistics such as minimum, maximum and average are included and expert comments on parameter values can be included. The method for data acquisition and selection during the preliminary site investigation phase is also described and a provisional data acquisition cost included.

Zero order approximation models take into account features such as altitude and topography and can be used on the basis of relevant data on catchments across Japan such as average river flow rate. The models can be used to consider differences in river properties such as length and width and, in the future, site specific data will be used to allow relationships between altitude and river water flow rate to be taken into account.

Future activities will be to further develop assessment models, to continue to update the manual and to improve the model for data selection to allow for site specific properties.

Whilst the models being developed and applied by NUMO for biosphere assessment are not specifically being applied to areas contaminated by the Fukushima accident (other organisations in Japan are responsible for such areas under Japanese law), there is interaction between the various organisations such that knowledge may be shared.

3.6 SWEDISH SAFETY ASSESSMENT FOR SFR

Eva Andersson and Sara Norden presented.

SFR is an existing repository for low and intermediate waste that is located 50 m below ground. SKB want to extend the repository to allow for the disposal of additional waste that will arise from extended operation of nuclear power plants and from decommissioning activities. The extension will be at a depth below the current facility. A new safety assessment is therefore required and is due to be submitted to the regulator in March 2014. Results of the previous assessment for SFR were only just below the regulatory dose limit during the lake phase of the assessment due to assessed possible release of C-14. However, large conservatisms were incorporated within the assessment. Much of the focus of the new assessment is therefore on C-14 to address these issues. In particular, the handling of human utilisation of the landscape during the lake phase is being considered in combination with the modelling of landscape development and radionuclide transport.

The Forsmark site is subject to land uplift that results in progression of ecosystem states from sea to mire and lake areas or terrestrial land. In the previous assessment, only release to a single lake was considered and questions have been raised as to whether this is realistic. The new landscape model therefore considers different discharge locations. The lake that received discharge in the past assessment will remain, but additional smaller lakes are also taken into account. Results indicate that the major discharge will be initially to marine basins and later to a wetland as the landscape develops.

Seven key landscape objects have been identified and the surface hydrological balance for each of these has been calculated.

In early safety assessments by SKB, humans were initially considered to utilise the landscape according to current dietary habits; however there is a large range in human habits and there was therefore a move in the SR Site assessment to considerations of an individual's energy requirements. These energy requirements were met according to the carbon productivity in each biosphere object. However, when the release of radionuclides occurs during a lake phase this approach leads to consumption of only fish, which is not realistic. In the current assessment therefore, energy requirements are again considered, but realistic constraints are applied to ensure that human utilisation assumptions are realistic. The utilisation assumptions have been based on consideration of self-sustaining communities over time (from prehistoric times to present day), giving rise to three human habits groups – hunter gatherer, early agriculture and industrial agriculture This work is described in Ambio (42(4) reached by open access [b]

For C-14, a new atmospheric model has been developed and the processes of methane oxidation and degassing has been considered. The accumulation of organic matter in soils and sediments, root uptake, the dilution of C-14 in aquatic foodwebs from terrestrial carbon inputs and seasonal variation of C-14 in biota have also been the subject of further consideration. Where they have been found to have a large influence on C-14 behaviour, they have been incorporated within the updated SFR assessment model. Where this is not the case they have been justifiably excluded. It is anticipated that the results of studies on C-14 will be made available in March 2014.

Not specific to C-14 has been work on Kd and CR values for both human and non-human biota dose assessments. The objective of this programme of work has been to find the best available and most probable element specific parameter values for given elements of concern, based on either site-specific observations or literature data in combination with general information on chemical analogues. Data from site characterisation programmes at Forsmark and Laxemar have been compiled, along with literature data within an MS access database. Where possible, site data for the radionuclides of interest are selected. Where such data are lacking, site data for an analogue element is selected or a parameter analogue. A combination of element and parameter analogues may then be applied to address remaining data gaps. A similar set of selection rules then apply to literature data when site data possibilities have been exhausted.

In compiling data within the database, a 3 step process is employed. Firstly, representative data (GM, GSD, min, max) for each given parameter and element case are selected from the total available dataset, based on statistical arguments alone (N, GSD). Sense checking is then performed by the automated system by comparing ranges in data from available data sources, for example through comparison of 5th and 95th percentiles. Manual evaluation is then used to look at each case and select parameter values for the assessment. If the selected value is reasonable and checks are in agreement then data selection and approval is easy. However, sense checks may indicate that ranges are not similar. Where this is the case, manual checks of the base data are required to consider the best approach for the selection of assessment data. Where there are no data for some parameters it is necessary to look at element/parameter analogues that can be applied and the

[b] http://link.springer.com/journal/13280/42/4/page/1

automated system can be instructed to then perform checks. Data compilation for the assessment is therefore an iterative process that is performed until a complete and as consistent as possible dataset of parameter values is achieved.

A comprehensive review process is in place. Four people are in charge of approving data with each having specific responsibilities. Each person's approvals are then reviewed internally before the resultant report is sent for external review.

The work on selection of parameter values and its reporting is on-going. Work on parameter correlations has not been specifically done to date. However, the parameters are measured within the same system and are thus considered appropriate. A report on Kd and CR parameterisation (SKB R-13-01) has been prepared and is currently under review. It is anticipated that publication will be by the end of 2013.SKB also has a large chemistry database as a result of site characterisation programmes. Much of the information is provided in reports SKB R-10-28 and SKB R-11-24, see www.skb.se/publications.

3.7 POSIVA BIOSPHERE ASSESSMENT BSA-2012

Ari Ikonen and Thomas Hjerpe presented.

The Posiva license submission for the construction of the Olkiluoto repository for spent nuclear fuel was made at the end of 2012 and it is currently under review. The supporting safety case reports are still progressing. The disposal concept is based around a KBS-3 multi-barrier system with the intention of total isolation of the waste. Excavation is already underway at the site and repository depth has been reached with some demonstration tunnels having been constructed.

The biosphere assessment is part of an integrated analysis whereby the biosphere is considered as part of the disposal system, but the surface environment is not afforded any safety function. A quantitative dose assessment is performed for the first 10k years post-closure. After this time, radionuclide flux from the geosphere is considered.

Fundamental questions for the safety assessment were:

- How does the surface system evolve over several millennia (10k years)?
- How do radionuclides migrate and accumulate within the biosphere?
- How do people utilise the environment and what effect does this have on the surface system?
- How are plants and animals exposed to radionuclides in the surface system?

In order to look at how the land may evolve over the next 10k years, knowledge of the historical development of the site is projected into the future. Human land-use considerations are constrained by regulations such that assessment scenarios are based on current human behaviour and assessment criteria are based on the current system of radiological protection. This is similar for biota, but it is acknowledged that the system for protection is still developing.

The biosphere assessment is comprised of a portfolio of reports.

The biosphere description report provides a scientific synthesis of what is known about site and its past development. Since the site is subject to land uplift, new land areas will emerge over the next 10k years, giving rise to feature that are not currently present at the site. It has therefore been necessary to consider a broader reference area than Olkiluoto Island itself in order to study the past development of biosphere features that are anticipated to emerge over time. Development lines have therefore been considered in terms of how the landscape has developed in the past and describing the ecosystems and biota as they are at present. For example, lakes will develop as a result of the isolation of sea regions. Shallow nutrient-rich lakes will then overgrow forming fens and mires and, ultimately, peat bogs. Throughout the descriptions of the development of the landscape, the aim is to be illustrative of prevailing conditions through the seasons and to describe key features. Utilisation of the land by people is also described, including descriptions of agricultural practices and what could be a hunter/gatherer lifestyle. Recreational use of the landscape is also described. The community structure of biota in different biotopes is also described and representative species identified and their habits summarised. Element fluxes have been calculated for the different biosphere systems and are also presented. Information presented throughout the report is based on best scientific knowledge, gained from an extensive site characterisation programme. The biosphere description report has recently been published (Posiva Report 2012-06).

In addition to the biosphere description report, a data basis report has also been prepared that documents the site- and regional-specific properties that are used as inputs to the assessment models. The report contains more site-specific data than past iterations and has benefited from increased understanding gained from interdisciplinary teams working together.

In the terrain and ecosystem modelling, the different drivers for landscape evolution have been identified and calculation cases have been formulated by varying these drivers. Some 30 different calculation cases have been analysed to show the effects of differences in development lines.

Land uplift is extrapolation from the past to the future, taking into account variations in sea level according to different climates. Lakes are formed from sinks in the topography. For peat bogs there is balance between production and decay and on the hydrological balance which determines the lateral extent of the bogs. Croplands are assumed to occupy a given proportion of the overall land area and are assumed to be formed primarily from clay or peat areas with the most suitable locations being allocated first. Due to continued land uplift, the site is effectively inland.

A reference case has been defined and variations such as maximum agriculture or no agriculture in which there are multiple peat bogs are then evaluated as variant cases. The location of defective canisters is also varied, giving rise to alternative release points to the south of the Island as compared with the reference case for which discharge is to the north. From the release point, biosphere objects can be contaminated by being downstream or as a result of irrigation activities. Most of the overall biosphere model area remains uncontaminated.

Overall, the most significant drivers for ecosystem and terrain development are land uplift and sea level change and whether or not croplands are present. Sedimentation in lakes also has some effect, but this has a much smaller influence. From studying the results from the different cases, two have been propagated to further modelling:

- The reference case

- A combination case that includes the fastest rate of coastline retreat, maximum extent of agriculture and sedimentation into lakes

The remainder of the cases were considered to be adequately covered by the propagated ones or argued not to be of high interest in terms of dose assessment. For example, increased sea level would result in a higher degree of mixing and thus lower concentrations and doses.

Surface and near-surface modelling has shown groundwater recharge in the centre of the island, giving rise to shallow and deep groundwater flows. The deep groundwater flows reach repository depth before flowing upward to surface discharge areas. The repository volume is modelled as one distinct hydrological unit. Within the repository, each canister position is considered in terms of where radionuclides would release to the surface environment from each, should there be a defect. Discharges coincide with low topographical areas.

SVAT modelling is applied to the whole site in 3D in order to allow fluxes from different biosphere compartments to be extracted as input to radionuclide transport modelling. The model is calibrated with and tested against present day site data and the same model and parameters are then applied to evaluate fluxes throughout the assessment time window.

Assessment criteria for human dose assessment have been stipulated by the regulator. Dose to the most exposed people should be below 0.1msv and average annual doses to other people should remain insignificantly low. For plants and animals, for which an assessment is also required under national regulations, assessed exposures are required to remain clearly below levels that, on the basis of best available scientific knowledge, would lead to a decline in biodiversity or other significant detriment to living populations. Whilst the protection target for people is radiation dose, the assessment of biota is based on exposure and no quantitative constraints are detailed.

The modelling approach is based around scenarios that are developed as a means by which uncertainties can be evaluated. As noted previously, only 2 repository cases are propagated to the landscape model.

A simple screening model, based on the IAEA SR-19 approach, has been applied to reduce the number of radionuclides that must be focused upon within the dose assessment. This allowed the number of radionuclides to be reduced from around 20 to 3 that are considered in all calculation cases and an additional 4 for some cases. This has allowed efficient allocation of resources on deriving parameter values for the key radionuclides in the landscape model.

In the reference case, there are around 200 landscape objects. The number of objects is partly due to the discharge occurring to a river with waters potentially being used to irrigate croplands that run along the length of the river downstream from the point of discharge. Each landscape object consists of a terrestrial and/or aquatic block that is further delineated into different habitats that can develop over time. Human activities are based on present day habits and there has been considerable effort placed on describing current behaviour. Dose from each biosphere object is calculated for one person and these are combined dose by summing dose from the worst terrestrial object with that of aquatic objects to derive dose from consumption of food and drinking water. This is repeated for each individual in the population (taken to be 6k people) to derive a dose distribution. The 20 most exposed people are selected as the most exposed group and remainder are then ‘other’ people in terms of the dose constraints set by regulator. Both variant and what if scenarios are also considered to allow uncertainties to be quantified. Human intrusion cases are also considered and are based on the BIOPROTA human intrusion report, but with scenarios adjusted for site conditions.

Peak annual dose to most exposed group in the reference case is ~1E-6 µSv resulting from releases due to a single defective canister. If additional canisters were defective, peak doses would not alter significantly as it is unlikely that the times and discharge points to the biosphere would be consistent. Consumption of fish from rivers was the principal contributor to the highest calculated doses with consumption of contaminated well water being the second highest contributor. The well would be sufficient to provide drinking water for only five persons. After these resources are utilised, the next greatest contributors to the highest doses are coastal fish and milk. These sources account for the doses received by the 20 most exposed people. For the remainder of the population, drinking water from a lake is the key exposure pathway. However, this is considered to be very conservative as it is very unlikely that the lake would be of sufficient size to sustain 6,000 people. For biota, dose rates are significantly below available screening values.

C-14 from well water consumption is the key contributor to dose. Food ingestion accounts for around 34%. However, diet assumptions are not realistic as they are protein dominated (i.e. fish). The contribution to dose from diet is therefore conservative.

For the variant and what if scenarios, the dose to the most exposed people remains well below dose constraints. Biota dose rates are also below screening values for all calculation cases, with the highest dose rates being calculated for a ‘zoo’ scenario whereby plants and animals are assumed to reside in the most contaminated biosphere object.

Uncertainty analysis indicates that doses vary by around 2 orders of magnitude according to near field assumptions. The key biosphere uncertainties arise from assumptions around diet profiles and the utilisation of resources from the most contaminated objects, irrespective of their location and assumptions around land use. Overall there is not much variation in dose with the different biosphere scenarios, but if total disposal system uncertainties are considered, for example varying discharge location, then dose can vary by up to 3 orders of magnitude. There is therefore a need to further investigate the sensitivity of dose to discharge location.

In contrast to the results from the SKB assessment, dose is reduced following breach of a failed canister. This is due to the peak in dose being from C-14 with other radionuclides not reaching the biosphere within the assessment time window. Whilst not included within the quantitative dose analysis, the fluxes of these radionuclides from the geosphere to the biosphere are analysed. If the time window were extended, Cs-135 and Ra-226 would give rise to the peak doses.

Having a real site is beneficial in terms of safety assessments as it is possible to rule out certain scenarios from knowledge gained in relation to the site characteristics. For example, in a generic assessment it may be required to consider the consumption of contaminated well water by a given population. However, through knowledge of the site, it may be justifiable to rule out such a exposure based on the ability of local aquifers to supply sufficient water to such a population. The size of fractures providing transport pathways can also be taken into account and the potential for drilling through these evaluated. Site knowledge therefore can provide substantial justification for important assessment assumptions.

3.8 CURRENT BIOSPHERE MODELLING ACTIVITIES AT SSM

Laura Limer presented.

SSM wants to ensure independent modelling capability to be able to review the SKB license application. A number of studies have therefore been undertaken.

A particular interest is on changing redox conditions and the influence on radionuclide migration in soil: the transition from wetland to agricultural land could result in a reduced water table that could result in acute release of accumulated radionuclides in agricultural soils as redox conditions change. Work therefore began in 2010 to compare simple and detailed process based soil redox models with a particular focus on Kd in these redox transition zones in both natural and agricultural ecosystems. A model developed by Ryk Klos for SSM has been compared with published redox data and similar dynamics in a soil layer are observed. Further consideration has been given to Kd in relation to oxic soil regions, partially saturated zones and saturated anoxic soils and to multiple soil-layer models with Kd assigned according to soil layer properties (similar to the approach developed by Mike Thorne for CIEMAT). In a simpler model with two soil layers, the upper is assumed to be considered oxic and correspond to the soil rooting zone, while the lower layer is anoxic. The different models have been considered in terms of the behaviour of Ra-226 and Se-79 totalling account of monthly or, alternatively, annual hydrological data. For Se-79, use of monthly data results in more movement of radionuclides compared with that arising from the use of annual data. As the number of soil layers is increased, the longer it takes for radionuclides to transition between upper and lower soil layers. Since Ra-226 is not redox sensitive its modelled behaviour was not responsive to differences between the use of monthly and annual hydrological data.

There is also considerable interest in modelling C-14 in the biosphere in both terrestrial and aquatic systems with work commencing in 2011 with an initial focus on terrestrial systems. Both operational and waste disposal models have been compared. Operational and waste disposal models apply a specific activity approach to plant uptake; root uptake is only considered within waste disposal models. Time steps considered and the source term (above or below) were variable, but both tend toward multiple atmospheric compartments. A key difference however is how C-12 is treated in plants. Waste disposal models tend to consider C-12 content as a constant whereas in operational models the C-12 content tends to increase as plants grow and therefore the specific activity ratio can decrease. In the C-14 model of the LLWR in the UK this is considered as a time interval with a specific activity flux into the plant throughout the growth period with the activity concentration at the time of harvest being an integral of this.

A C-14 model (SSPAM14C) has been developed for SSM and tested against available data. The plant system is represented by both above and below ground compartments, soils include various organic matter compartments and the atmosphere is represented by two compartments to represent diffusion and turbulent processes. To allow the model to be applied to both operational releases and waste disposal applications the source term can be from above or below ground and can be in the form of a gaseous or aqueous form. Plant biomass can be represented statically or dynamically.

The model has been validated against data from a study performed by Imperial College in the 1990s that looked at the dynamics of C-14 in atmosphere and crops following a spiked atmospheric release. C-14 in soils was not measured. One data set was selected and used as a source to the turbulent atmospheric compartment in the model. Model parameters were then optimised to the experimental data set. The model was found to reproduce C-14 in the above ground plant, but the below ground plant compartment was not so accurate. If atmospheric pumping is applied to increase movement of C-14 through the system then the results for the below ground plant compartment were improved the accuracy of the model in terms of soil concentrations could not be verified due to lack of experimental data. As such the complexity of the soil model cannot necessarily be justified; simplification of the soil model is an area of current development. Further work will be done in relation to additional Imperial College experimental results.

More recently, consideration has been given to the modelling of C-14 in aquatic ecosystems. Work performed in BIOMOVS II on C-14 model testing against field data from Canadian Shield lake experiments has been reviewed. Models were applied in this study by AECL, QuantiSci and Studsvik. Since this time, further models have been developed by SKB, Posiva and EdF. This information was also reviewed as part of the on-going BIOPROTA C-14 project, the recent workshop of which indicated that seawater data for C-14 may be available. Work within SSM has focussed to date on what justification there is for further development of models from those applied to the Shield lake experiments and how subsequent models vary from these. Equations from a model developed by Avila and Pröhl have been applied to the Shield lake data to determine the most effective approach to representing data observations. Differential equations were found to give the best fit against the experimental data. It is intended that work will continue in this regard through participation of SSM in the on-going C-14 programme within BIOPROTA.

Future work on soil-plant modelling is also planned. This will look at the role of bioturbation in governing radionuclide behaviour and whether a CR or dynamic approach to plant uptake is preferable. SSM also intend to continue to contribute to the BIOPROTA programme of work on the interface between the geosphere and biosphere.

3.9 PROGRESS AND PERSPECTIVES OF ENRESA & CIEMAT RESEARCH PROGRAMME FOR RADIOACTIVE WASTE ENVIRONMENTAL SAFETY ASSESSMENT

CIEMAT is a technical support organisation and is involved in research programmes connected to ENRESA that are aimed at improving the knowledge base and assessment models for radioactive waste disposal. CIEMAT is responsible for the biosphere modelling aspects of the overall research programme.

The majority of radioactive waste in Spain is low and intermediate level (L/ILW) and very low-level waste (VLLW), and most will be derived from decommissioning activities. There are only small quantities of HLW. In addition there are legacy sites that require consideration, including uranium mines and some installations where environmental remediation activities are required.

The main facility for L/ILW and VLLW disposal is at El Cabril which has sufficient capacity to receive wastes until 2020. Extension of the facility beyond this time is not planned as yet. Research programmes for the site are currently focussed around the performance of concrete, metallic and clay based materials for barriers and optimisation of the covering layer for the facility.

L/ILW arriving at El Cabril is conditioned at site with the exception of that arriving from the nuclear power plants that has largely been conditioned prior to transport. Waste is disposed in drums or containers that are emplaced within concrete containers. When a container is full, the drums are immobilised by means of injected mortar. The block is then placed in the disposal cell, which is a structure of reinforced concrete. There are two disposal areas, each of which is subject to continuous monitoring of water collected from the disposal cells. The facility will be subject to a 300 year site surveillance and control phase. The VLLW store is similar, but barriers are not so sophisticated. The VLLW facility will be subject to a 60-year site surveillance and control phase.

According to the ENRESA research plan, the strategy for HLW is to strengthen the current temporary storage capacity with disposal options being considered in the future. Centralised temporary storage of HLW from all sites in one facility is preferred. A location close to Madrid has been identified and the capacity of the facility will be sufficient to allow storage of all spent fuel from the lifetime of the nuclear power plants (some 40-50 years). No further nuclear power plant build is anticipated in Spain.

The Spanish programme for geological disposal of HLW was halted in 2000. However there was a desire to maintain the level of knowledge relating to safety assessments and work has therefore been on-going in this field within CIEMAT. No decision on the final strategy for HLW is expected for the next 12-20 years.

The last environmental assessment for the El Cabril site was in 2002 and this is now being revisited and improvements in assessment models and the approach to human intrusion assessments are desired to take account of new developments internationally in assessment approaches. This is particularly the case for C-14 for which the previous assessment model was shown to over-estimate C-14 doses. The influence of climate change on assessment model output is also an area of interest.

In addition to activities relating to waste disposal from nuclear power plants, improved knowledge on the behaviour of uranium-series radionuclides is required to address the issue of NORM industry waste in Spain. A model for U-238 series radionuclides has been developed and it is hoped to develop this further to allow consideration of the spatial distribution of radionuclides. Further collaboration on uranium series radionuclides through the BIOPROTA and MODARIA programmes is planned. The safety case approach employed for NORM wastes will be consistent with that for other radioactive wastes in Spain and work is on-going to bring together the different industries and to facilitate dialogue and the sharing of expertise between these.

Activities are also planned to investigate how phosphate mining wastes should best be managed, in line with new regulations on NORM wastes. Reducing the economic cost of NORM management is desired.

Biota dose assessments are also planned. It is intended that the ERICA assessment approach will be applied to both El Cabril and NORM disposal sites and continued collaboration on dose assessment issues will continue. Ultimately it is hoped that both human and biota dose assessment methods can be combined within one screening tool.

ENRESA are also becoming interested in the assessment of toxic wastes and in the future activities may therefore look at combining NORM and conventional wastes. Multi-attribute analysis is also an area of increasing interest in terms of supporting integrated safety assessments.

3.10 EPRI'S COMPARATIVE RISK ASSESSMENT TOOL

Andrew Sowder presented.

EPRI was founded in 1972 and is an independent, non-profit centre for public interest energy and environmental research, supported by utilities. The overall purpose is to provide technical support to the provision of power and to ensure safe and reliable energy production. Initially the centre was focussed in the US but is now international. There are in excess of 450 members that encompass more than 70% of the global nuclear energy providers.

EPRI used to be active in the area of performance assessments and has been credited with establishing performance assessment early on and were an independent voice in keeping the Yucca Mountain programme on track. However, now that the Yucca Mountain programme has been terminated, the US will not have a repository for nuclear waste until well after the closure of the current operating fleet of nuclear reactors.

Each operating reactor is required to have a contract with the government for the transfer of spent fuel upon closure. Due to the termination of Yucca Mountain, DoE contracts for new build requires on-site storage for a minimum 80 year period. The HLW focus of EPRI is therefore on research and development activities to support the technical basis for wet and dry storage technologies and a $70 million award has recently been made for a demonstration programme to deploy casks to examine fuel burn up under storage conditions. A key objective is to extend licenses for dry storage units that have already been deployed. For low burn-up fuels a 60 year storage license can be issued, but for high burn-up fuels the storage period is 20 years and some storage facilities already exceed this. The storage fuel burn-up programme aims to address issues around this and to improve storage capacities in the longer term. It is an international programme with 20 participating countries.

Whilst storage is now the central focus of EPRI, the utilities eventually want waste moved off-site so both transport and disposal are still interest areas, but EPRI is largely working to remain engaged in these areas at the current time. Work is however continuing on the future of advanced fuel cycle options.

In the US DoE 2010 roadmap, a series of research and development priorities were identified. The research programmes are large and require long-term effort. However there are a number of short term constraints that add to the complexity. These include cycles in policy (elections) and budgets.

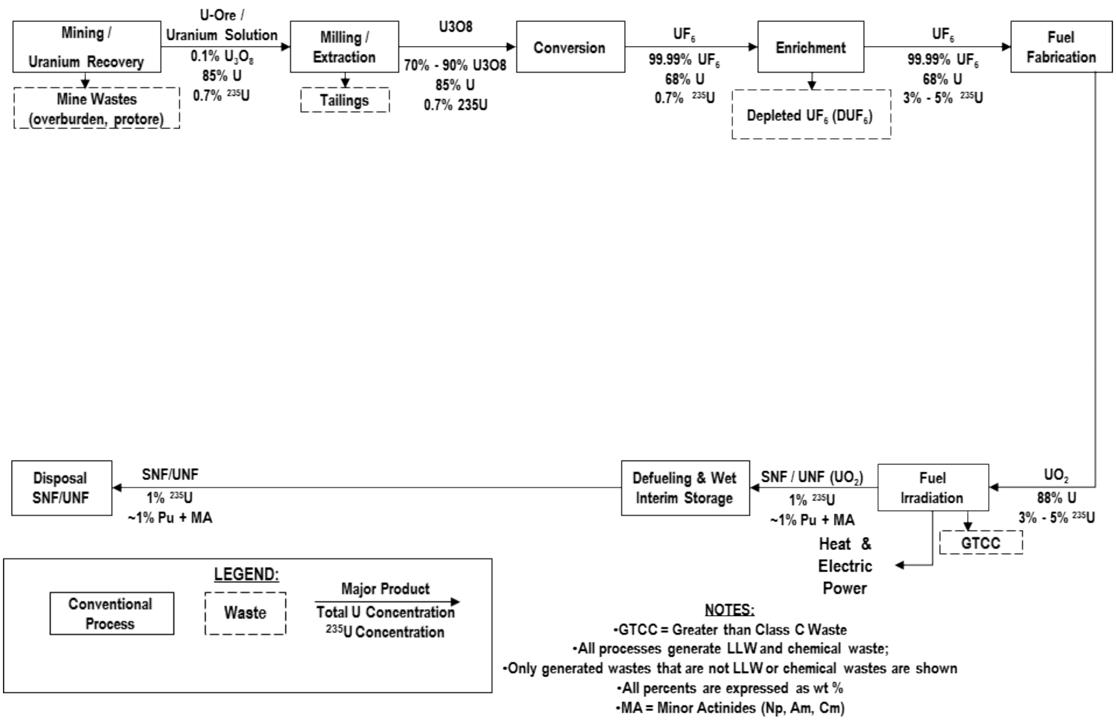
In terms of advanced fuel cycles, it is considered too early to decide whether to pursue this or not so options are being kept open and all options for the nuclear cycle are being considered. Options will be narrowed as the new build programme moves forward. There will be considerable work required to license new technologies and regulators need to be informed of developments to ensure that the regulatory and licensing framework is in place and work is required to progress toward the production of fuel for advanced technologies. A study of the gaps in research and development activities related to the nuclear fuel cycle has been undertaken and reported in ‘The future of the nuclear fuel cycle: and interdisciplinary MIT study’. This has provided the launching pad for developing and maintaining an independent assessment capability by EPRI and to develop an independent capacity to evaluate drawbacks of cycle options and to assess human and environmental health impacts arising from the nuclear fuel cycle. There is also an objective to develop a straightforward metric for evaluating non-proliferation and security risks associated with fuel cycle options.

A decision framework structure has been developed. The starting point is to establish the strategy as to what is being done and why. This is then followed by a more tactical assessment prior to evaluating readiness in terms of technology, infrastructure and institutional readiness. The assessments become increasingly detailed. The framework structure is being applied to the fuel cycle for which the strategy is based around the need for nuclear power. The strategic assessment also considers factors such as resource utilisation and energy security, waste management safety and operational safety, licensing and regulatory compliance, economic competitiveness and protection of people, workers and the environment.

An annual workshop programme is being established and the report of the 2012 workshop has been published (EPRI report 1026556). Reports are also available on the decision framework and risk assessment tool (and all are available from the EPRI website).

In terms of the assessment toolbox, the fuel cycle is broken down by facility and conceptual models developed to allow occupational health and public and environmental impact assessments (both radiological and non-radiological) to be undertaken. The US does not take the traditional fuel cycle view (Figure 3-2a); rather the entire cycle (Figure 3-2b) is considered. This view of the cycle requires aspects such as enrichment of high assay tails, down-blending, disposal of depleted uranium tails in hexafluoride form, and industrial hazards from non-radioactive materials such as fluoride gas.

a



b

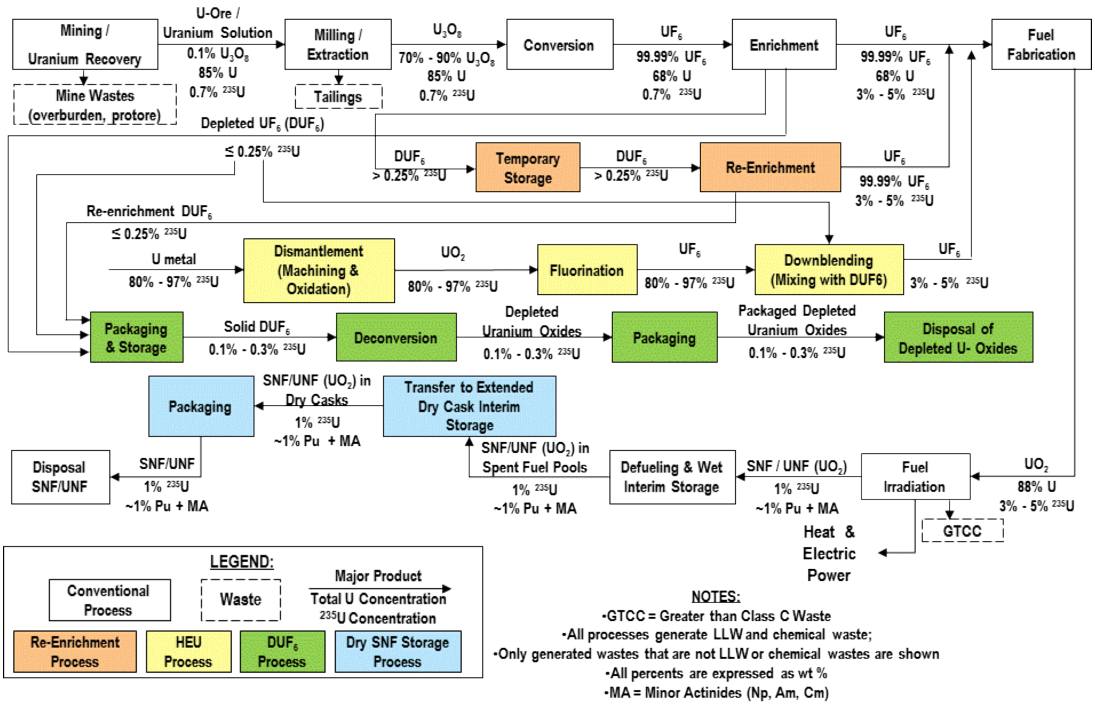


Figure 3-2. Fuel cycle in terms of the traditional view (a) and the US approach (b).

In establishing a conceptual model, the initial focus has been on occupational dose and whether there is sufficient data available to support the assessment. Once a qualitative assessment has been completed, the move is then toward a quantitative analysis using a more sophisticated model for dynamic systems with various feedback loops. Contributions to dose arising from different facilities can be tracked and stock materials can be tracked to identify requirements for new sources and when new facilities will come on line. The impact of different fuel sources can also be evaluated. For example, in the past when traditional uranium mining methods were employed, the highest doses throughout the fuel cycle were associated with mining activities; however, with improved mining technologies, reactors and mining switched as the major occupational dose contributors due to the reduction in mining hazards. If there is a move to an advanced fuel cycle, risks will again be reduced due to the smaller number of workers required on site. The risk profile is therefore changed in response to technological developments and overall doses across the industry have reduced.

Much of the focus of advanced fuel cycles is on improving the waste cycle. The cycling of fuel must therefore be considered and a whole-cycle view is required to ensure that decisions are made according to a single coherent model that takes a holistic view of nuclear energy systems.

EPRI continues to maintain an interest in low level waste disposal safety assessment, including management of wastes containing C-14.

3.11 UPDATE ON PROJECT ECORISK: WATER FLOW & SOLUTE TRANSPORT MODEL

Talal al Mahaini presented.

ECORISK is a collaborative project sponsored by Belspo. Forests sequester carbon within tree biomass and can decrease the impact of fossil fuel emissions through incorporation into wood. ECORISK aims to evaluate the impacts of climate change on forests (e.g. carbon nutrient storage and pollutant migration), to consider decision making in terms of reducing impacts of extreme events (e.g. extreme droughts) on sustainable production of woody biomass through the evaluation of extreme events, and to optimise nuclear waste management policy since trees act as biological pumps.

The project has five work packages. The first aims to provide climate data to drive models. The second then looks at nutrient cycling at soil/root interface. Work package 3, run by SCK then aims to develop a cycling model for flow and transport of water and solutes (ECOFLOW). Work packages 4 and 5 then looks at the development of a forest response model that considers environmental stresses and the development of a decision support tool, respectively. The focus of SCK is therefore to develop a model that simulates water flow and solute transport that is realistic, but not too complex. It is intended that the model could be coupled to other models.

A long list of parameters has been identified from review of other forest models and there is therefore a need to try and simplify flow and solute transport. The starting point has been the conceptualisation of a forest model and identifying the key processes (climate control and evapotranspiration, soil water flow, solute transport, root uptake and retardation). An interaction matrix is evolving over time and an ECOFLOW prototype has been developed within model maker.

In moving from no stress to stress conditions (in terms of water availability), parameter values are changed leading to affects on evapotranspiration. A water reduction model is used to reduce uptake in response to water stress. Hydrus-1D, a sophisticated model tool, is being used to validate the model. It solves Richard's model numerically and is well tested and validated and also has a good user interface. However, it is not combined with geochemistry and coupling to other models can be complex. For validation purposes, two soils were selected, sand and clay, with different hydrological characteristics. A 1 m deep soil profile with free drainage below was assumed for each and both ECOFLOW and Hydrus-1D were applied. The output from both models was very similar. Models were also applied considering vegetation in a free-draining soil scenario and again good agreement between models was observed. Results indicate that, unlike sands, clays have lower hydraulic conductivity and higher ability to retain water hence a greater amount of water is available for plant uptake that in turn leads to higher plant uptake. When a shallow water table scenario was considered, the results were not is such good agreement between the models and further analysis of differences is required.

Work is now on-going to look at the coupling between solute transport and hydrology and environmental parameter variables including redox must be considered. In general variable Kd models are favoured since they are simple and are a step forward from constant Kd approaches.

The next steps in the programme will be to apply models to soils with varying structure and depth and to simulate root growth and link to environmental variables such as temperature. Work will also continue on the validation and testing of the model against other models and data. The ECOFLOW model will also be coupled to other process models to allow simulation of forest ecosystems throughout Belgium.

It was noted that tools for connecting models such as MIKE-SHE and PHREEQC are being considered by SKB and Amphos21 that will allow spatial resolution to be mapped. Overall there is a need to consider how small box models can be applied to a larger area such that spatial scales are taken into account.

3.12 SSM'S LICENSING REVIEW

Bjorn Dverstorp presented.

In 2011 SKB submitted their license application for the construction and operation of spent fuel disposal facility in Sweden, based on the KBS3 disposal concept. In response, a multidisciplinary licensing review project has been established to review the submission.

The review process involves two organisations – SSM and the land and environmental court. There is interaction between both bodies, but in the end it will be the government that makes the final decision, having consulted with the municipality involved. This will be the final time in the process that municipalities will have a veto right. The review process post-submission involves docketing (a formal check that the application meets regulatory requirements), an initial review, a main review and reporting phases.

The initial review phase, with the primary documents and some secondary documents being reviewed for overall quality and data gaps, has been completed. The initial review resulted in requests for complimentary information and identified the safety critical issues that were to be focussed upon in the main review phase that is now underway and is expected to last two years. The process involves SSM reading through the submitted documents and assigning tasks to external experts for detailed review. The review findings by SSM's external experts are documented in technical notes that are made available on the SSM website. These comments reflect the views of experts and not SSM. Independent modelling is conducted (as noted in section 3.8) with the first phase of this programme being aimed at reproducing substantial parts of SKB's consequence analysis. Further, during the initial review phase, a national consultation was also undertaken that included the municipalities involved, universities, county boards, non-governmental organisations, other government authorities etc. The NEA has also organised an international peer review for which a report is available on the SSM website.

As a result of the review process to date, around 60 requests for complimentary information have been sent to SKB who are working on providing this information. All responses are due by the end of 2013. A statement on the submission, from the initial review, has been submitted by SSM to the land and environment court.

One of the critical review issues identified for the main review phase involves canister integrity in that the disposal concept relies heavily on containment and, out of 6,000 canisters the failure rate is extremely low throughout the 1 million year assessment timeframe. Questions have therefore been raised as to rates of corrosion and copper creep (whether high pressure could lead to a common load failure). Questions also arise around long-term re-saturation since the assessment relies on safety functions that assume that water will infiltrate into the facility. The ability to emplace canisters safely and perform back-fill operations also requires demonstration: the assessment assumes no errors and hence the quality required and assumed in the assessment must be demonstrated.

The licensing process for the spent fuel repository is separate from that for ILW and other wastes and facilities are therefore considered in their own right. SKB's assumption is that the construction of a facility for the disposal of spent fuel will start in 2019 whereas a facility for ILW is likely to be some 20 years later.

3.13 LLWR NEWS AND FUTURE INTERESTS

Trevor Sumerling presented.

The 2011 environmental safety case (ESC) produced by Low Level Waste Repository Ltd (LLWR) addressed inadequacies of the previous assessment that had been done by BNF for the disposal facility in the north west of England. The previous assessment resulted in restricted disposals and the site and, as a consequence, the need for storage rather than disposal. Unless a new permit is attained, Vault 8 is in an unsustainable situation with only a small capacity remaining.

The ESC submitted contains 3 levels of documents (available from the LLWR website, http://llwrsite.com/national-repository/key-activities/esc/esc-documentation/) that have been through a review process, including review by the Environment Agency of England and Wales. A permit application has not yet been submitted. Rather, the current status is that there are discussions on-going to clarify issues and address any misunderstandings in the ESC submission that have been issued as around 70 formal issue resolution forms. Around 90% of these have been responded to, some of which were challenging, and work is underway to address the remaining issues. A permit application, based on the 2011 ESC submission, is due to be made in June or July that will take into account additional development work that has arisen in response to resolution forms. The application will specify Waste Acceptance Criteria (WAC) with conditions. Planning permission from Cumbria County Council is also required and an application was submitted in June 2011. However the county council will not grant permission unless the Environment Agency grants a permit, but vice versa, the Environment Agency cannot grant a permit unless permission has been granted by the county council. An Article 37 submission has also been made and the EC is expected to approve since impacts are localised.

Vault 8 was commissioned in 2012 and is being used to store waste prior to disposal. Currently waste is stacked to a height of around 7.5 m. Waste containers in Vault 9 are also stored. The permit application will aim to move from storage to disposal and allow for the phased construction of additional vaults. The final cap is intended to be a dome structure and this will provide for significant additional disposal volume (up to around 11 ISO freights in the middle of the vaults). Combined with the construction of additional vaults, it is anticipated that there will be sufficient disposal capacity until at least 2080.

Currently the site is operating under the existing permit and both the ESC and site development plan, itself developed from the ESC, are being applied where permissible under the current permit. A new permit will be applied for in the summer (2013). Once this has been submitted it will trigger a statutory process that must be completed within a fixed timescale, which is why there is a gap between ESC and permit applications to allow issues to be addressed. A decision on the permit application will include public consultation. The permit is anticipated to be granted in the spring of 2014. It is intended that the ESC will be maintained as a ‘live’ safety case with formal change control.

For non-radionuclides, it is proposed that impacts be controlled in a similar way as for radiological impacts by defining repository capacities. In the ESC, the same models for radionuclides and other contaminants were applied where feasible. There are four groups of non-radioactive materials considered at the site that vary in control measures:

- Quantities recorded but not controlled, e.g. Fe, Cr, Co, Cu, Zn, Sn (in metallic form), inorganic fluorides and phosphates
- Capacities defined, e.g. Pb, As, Be, Cd, cyanides, tributyl phosphate
- Others – may be accepted under a variation
- Special cases (e.g. asbestos).

Mercury is not an issue for LLWR as no significant disposals to LLWR have occurred.

It is intended that information on non-radiological materials will be improved upon in future waste inventory, and where possible, for past disposals. Where disposals do not meet the WAC, an operator is required to demonstrate that disposal represents the Best Available Technique.

In terms of biosphere assessment, future key interests are on improving models for the period of authorisation when the site remains under regulatory control to allow better use of available monitoring, and in building confidence in C-14 models and the supporting scientific basis.

Due to the location of the repository, a key issue is coastal erosion and models for estimating dispersion in sediments and water need to be refined in order to take account of waste form as the facility is eroded in the future and to have a greater understanding of exposure to discrete items (e.g. hot particles). There are known particles in the LLWR, including the potential for flecks of radium paint of high activity concentration. Small fragments of spent fuel may also be present. Whilst the average activity in a disposal is known, it is not possible to determine the nature of all wastes and this can be an important consideration for dose distribution risks. Improved documentation is therefore required and the Environment Agency has written additional guidance on disposing of waste that may contain radioactive particles.

4. NEWS FROM OTHER PROJECTS AND PROGRAMMES

An update on other projects and programmes relevant to BIOPROTA, as presented during the workshop, is summarised below.

4.1 IAEA MODARIA PROGRAM.

The IAEA program includes the following Working Groups which are relevant to BIOPROTA activities:

- WG1 - Remediation strategies and decision aiding techniques
- WG3 - Application of models for assessing radiological impacts arising from NORM and radioactively contaminated legacy sites to support the management of remediation
- WG4 - Analysis of radioecological data in IAEA Technical Reports Series publications to identify key radionuclides and associated parameter values for human and wildlife exposure assessment
- WG6 - Common framework for addressing environmental change in long term safety assessments of radioactive waste disposal facilities
- WG8 - Biota modelling: Further development of transfer and exposure models and application to scenarios
- WG9 - Models for assessing radiation effects on populations of wildlife species

Most relevant is WG6 which aims to update the EU BIOCLIM project completed in 2004, on long-term climate modelling and its regional downscaling to take account of examples of its application and more recent developments. The objectives are:

- To define key processes which drive environmental change (mainly climate), and describe how a relevant future may develop on a global scale. These drivers are quantitative and can be extracted from existing scientific consensus on global historical climate evolution.
- To develop a conceptual framework that is valid on a global scale, and consider how that can be downscaled to provide information that is needed for site specific assessments.
- To apply the conceptual framework to case studies, to illustrate evolution of site characteristics and the implications for the dose assessment models.

The work is organised in 3 sub-groups:

- SG1: Global Climate and Climate Related Processes (led by SKB),
- SG2: Applying Narratives for Relevant Futures (Description of Site Development) to Specific Sites (led by Helmholtz-Zentrum, München), and
- SG3: Analysing Process Understanding and Confidence (led by SSM).

More information can be obtained from Tobias Lindborg (SKB), who is the WG6 leader Tobias.Lindborg[at]skb.se. The work is also a natural extension of IAEA EMRAS II WG3 report: Environmental Change in Post-Closure Safety Assessment of Solid Radioactive Waste Repositories, a draft copy of which can be obtained from Tobias.

4.2 STRATEGY FOR ALLIED RADIOECOLOGY (STAR)

A strategic research agenda (SRA) for radioecology is being developed through STAR - http://www.er-alliance.org/. BIOPROTA members have previously provided input to the development of the SRA via a presentation that was given by Mike Thorne to a STAR workshop in 2012. In a waste disposal context, the main interests are on characterising the area local to facility, on key radionuclides contributing to dose in the long-term (and to justify screening models) and on developing comprehensive models for relevant radionuclides. Environmental change over timescales of interest is also an important consideration. one of the strategic aims of STAR is to understand mechanisms of radiation exposure across all species of non-human biota. However, the duration of the programme is only 20 years, and that level of understanding has not been gained for one species, humans, during a comparable timeframe. There is also an objective to consider multi-stressors and links to other research initiatives are required in this regard. The Strategic Research Agenda is thus very ambitious and the need for a long term view is acknowledged.

4.3 CERAD

CERAD is the Centre of Excellence in Environmental Radioactivity, established by the Norwegian University of Life Sciences (UMB) in partnership with the Norwegian Radiation Protection Authority (NRPA) and in collaboration other Norwegian institutes and key experts from other countries. Theoverall objective is to provide new scientific knowledge and tools for better protection of people and the environment from harmful effects of radiation, based ona programme of targeted focused long-term research on:

- Source terms and release scenarios
- Ecosystem transfer
- Biological responses
- Impact and risk assessments
- Ultraviolet radiation and the combined effects of UV and radioactivity.

Further information on CERAD is provided at www.umb.no/cerad/. .

4.4 NCORE (NATIONAL CENTRE FOR RADIOECOLGY)

Managed by the Savannah River National laboratory (SREL), NCORE was set up in recognition of the immediate need to build the pool of radioecology expertise in the USA and elsewhere due to the renewed and growing interest in nuclear energy and the continuing decommissioning and subsequent transitioning of legacy waste sites to long-term stewardship. NCORE participants include radioecologists from SREL and universities across the USA, including Oregon State, and from laboratories in France and the Ukraine. Recognised priority areas of related to BIOPROTA activities include:

Examples of priority areas:

- Address data gaps and validate transfer factors, many of which were collected in the 1970s, and are used in our current models to calculate doses to the public.
- Address areas of surface contamination on sites where contamination includes both radionuclides and heavy metals. Subsurface contamination has been the focus of DOE-EM activities in previous years but areas with surface contamination are an issue at all DOE sites, requiring further consideration of biota effects, remediation strategies, and transport and fate of contaminants such as uranium and nickel released at industrial sites.

For more information see: http://srnl.doe.gov/newsroom/2011news/012611.htm

4.5 HIDRA (HUMAN INTRUSION IN THE CONTEXT OF DISPOSAL OF RADIOACTIVE WASTE)

HIDRA is an IAEA project which aims to describe considerations for addressing future human actions in post-closure safety assessment of radioactive waste disposal and the use of those assessments to optimise siting, design and waste acceptance criteria within the context of a safety case. It is a 2 year project that started in the autumn of 2012 and it is intended that the output will be reported in an IAEA TecDoc. There are four working groups:

- WG1 - Technical details and scenario formulations.
- WG2 – societal aspects such as state of knowledge.
- WG3 – how to optimise design to prevent HI.
- WG4 – an integration group to develop a methodology and guidance on how to apply this to different stages of the life cycle of facility, including WAC.

Whilst intended as a 2 year programme, it is possible that this could be extended. The next meeting will be held 4 – 8 November 2013 in Vienna. The IAEA co-ordinator is Yumiko Kumano (Y.kumano[at]iaea.org), but further information can also be obtained from Eva Andersson at SKB (Eva.Andersso[at]skb.se).

5. NEW PROJECT PROPOSALS AND PLANNING FOR 2014

New project proposals presented during the workshop are described briefly below. These relate to dynamic modelling between soil, vegetation and atmosphere (SVAT) in a perennial ecosystem; a forward programme for reducing C-14 assessment uncertainties; approaches to address correlations in assessment parameter values; and a field study to investigate radiation effects in wolf populations exposed to radiation in the Chernobyl exclusion zone, taking into account spatial movement and exposure levels. Initial versions of proposals for the work programmes on dynamic modelling and C-14 were distributed to BIOPROTA members prior to the workshop. Updated and additional proposals will be distributed to members as they are made available to the BIOPROTA Technical Secretariat (TS).

5.1 DYNAMIC MODELLING OF SOIL-VEGETATION-ATMOSPHERE TRANSFER IN PERENNIAL ECOSYSTEMS

Jordi Vives i Battle presented.

A PhD project is proposed, with matched funding being sought from BIOPROTA members. The objective is to develop a forest ecosystem model for the long-term assessment of the cycling of radionuclides within forests. The work programme would address a gap in current modelling capabilities between radiological assessment and forest ecological models and would aim to be simple enough to remain practical for implementation. A SVAT approach is proposed with water flows being the basis for the transfer of energy fluxes that elements then follow. The output would be a process based model integrating both radionuclide and ecological processes that could be further developed at a later stage to perennial and annual crops. The programme would be linked to the ECORISK project (see section 3.11) and, based on dynamic modelling of chemical, physical and biological processes, is a direct response to the STAR strategic research agenda. The project also follows from other research work performed by SCK.

A student has been identified that has just completed an MSc focussed on forest-element cycling data and partitioning within forests. The student has a good understanding of the mathematics of nature.

The project will begin with a focus on the Mol forest due to the wealth of data available from monitoring and research activities. The focus of research could be extended to other areas at a later stage should data be available and depending upon the interest of project sponsors. The study will not necessarily be limited to considerations on radionuclide cycling but could also include nutrient and heavy metal cycling.

Five work packages have been identified. The first would involve a review of SVAT modelling and would evaluate relevant processes. Work package 2 would then aim to gather data and assemble databases focussing realistically on radionuclides relevant to the nuclear industry and Belgian forests. Forest model design and implementation (including development of interaction matrices and mathematical formulation of the main processes) would then follow in work package 3 with coupling of the forest model to simple deposition and hydrological models, such as the water transport model developed in relation to ECORISK forming work package 4. The final work package would then involve projecting element cycling and distribution in other Mol pine / oak forests with simple climate projections (data permitting). The output will be a model maker derived model that is developed from a thorough understanding of the science of the system. Use of model maker as the platform allows for revisions to be made as the model develops.

Key questions to be evaluated include:

- Vegetation as a biological pump; what is the influence of plant type?
- Biological retardation- how does living tissue affect radionuclide transport?
- What are the fluxes and mass balances throughout plants and how does this alter with plant growth?
- How effective is root uptake as a pathway for radionuclides to enter plants and what is the role of photosynthesis in terms of element cycling?

The model, once developed, would allow the overall approach to be tested and to isolate key FEPs through comparison with other models. By gaining a thorough understanding of the key processes it will be possible to adapt to other assessment situations, e.g. different climates.

The PhD will cost around €50k per year over 4 years, excluding bench fees and supervision time. The budget being requested from BIOPROTA is half of this (i.e. €25k Euro per year for 4 years). It is proposed that a small consortium of three or four partners could be formed that would constitute a stakeholder group that would be kept informed throughout the duration of the project. Funders would also receive progress report and results as they become available and would have the opportunity to propose case studies to which the model could be applied as it develops. Annual meetings on progress and priorities could be arranged as required.

Due to tight timescales in approving PhD research programmes within SCK, a prompt decision in principle to support the project was requested; please contact Jordi Vives i Battle at jvibatll@SCKCEN.BE. Interest had already been noted from both Andra and Posiva.

5.2 C-14 FORWARD PLAN

Mike Thorne presented.

Potential future activities were identified arising from the work described in Section 2.1. These ideas have been aggregated into the following four tasks for consideration in a future work programme and are described below.

Task 1 – Review the conceptual and mathematical basis of models currently being used or developed to represent C-14 transport in soil-plant systems and undertake a new and expanded inter-comparison between those models for test cases relevant to solid radioactive waste disposal.

The enhanced LLWR model, the model developed for SKB, the Nagra NC14M model and the model developed for SSM, as well as any others proposed by participants could all be reviewed. These models are not fully independent due to similarities in those contributing to development, but they appear to have structural differences. Input required would be diagrams with commentary showing conceptual structures, compilation of equations (all in common nomenclature), and commonality of units. Input would be used to identify where there are differences and a commentary on the possible significance of the differences could then be developed. Test calculations could be performed to quantify the significance of these differences in dose terms and the conditions or circumstances in which those differences are important. The aim of the inter-comparison is to see whether there is a consensus in model results when a test case has been defined clearly and unambiguously, and parameter values appropriate to the different model formulations have been made consistent, to as large a degree as possible.

Task 2 – Compare results from simulations undertaken with models currently being used or developed to represent C-14 transport in soil-plant systems with available field and experimental data.

Data sets will need to be obtained and processed prior to being used to compare models. Several possible examples have been identified as discussed in Section 2.1. It is not proposed that a blind validation be performed, rather modellers will be able to adapt equations / parameters, and an audit trail of modifications developed. NDA-RWMD experimental work has been designed specifically for calibration exercises for models of C-14 release from sub-soils. Other data sets tend to be more based around atmospheric discharges and dispersion. Use of the RWMD data would therefore constitute a strong test of models due to the focus on the sub-soil release pathway.

Task 3 – Undertake a modelling study of the Duke Swamp area at Chalk River in order to explore whether the observed changing distribution of C-14 in the swamp can be explained through application of physically based mathematical modelling.

The first stage would be to identify, acquire and evaluate available information concerning the hydrology of, and distribution of C-14 in, Duke Swamp. This would include both measurement data and model interpretations of those measurement data. This would require initial discussions with AECL to determine the extent of the data that exist, the modelling studies that have already been undertaken, and the availability of the data for use by BIOPROTA participants. This work would not be a validation of models against the data. Rather, the models would be used to interpret the data and shed light on the processes governing the behaviour of C-14 in wetlands. AECL has been contacted.

Task 4 – Review the general conceptual and mathematical approaches appropriate to modelling C-14 transport in different ecological contexts, with particular emphasis on models applicable to streams, rivers and lakes.

Different model approaches would be reviewed and, on the basis of the review, it may be possible to develop an enhanced conceptual model for freshwater ecosystems. The available models would be audited against the overall conceptual model of C-14 cycling in freshwater ecosystems to determine how they could be used individually or in combination to represent the transport and distribution of C-14 in freshwater ecosystems. The output would be a report summarising the models available, identifying their capabilities and describing, as appropriate, the conceptual and mathematical structure of an enhanced model, or models, for representing the transport and distribution of C-14 in freshwater ecosystems. At a later stage, the models could be applied to assess environmental concentrations of C-14 arising from operational discharges into rivers and results compared with monitoring data.

The technical support team being proposed is consistent with that for the most recent C-14 work programme, but additional support is invited. It is noted that there are special areas such as Duke Swamp for which specialist support in acquiring and/or interpreting data may be beneficial. The timeframe for each task is anticipated to be around 12 months. However, if all 4 tasks are taken forward a time period of 15 months is envisaged. Any combination of tasks can be considered with each potentially being published as a standalone report.

5.3 MANAGING CORRELATIONS IN ASSESSMENTS

Graham Smith presented.

The suggestion has been made by several organisations to review parameter correlations in assessments.

IAEA TRS 472: Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments notes that "modellers and end users can also consider using existing single and multiple correlations between soil properties and Kd, especially in those cases where the mechanisms behind radionuclide interaction are well known." It is clear that some parameters are correlated, and in order not to select or sample meaningless combinations of parameter values this issue must be addressed. A so-called Derived approach implies finding an analytical or empirical relationship between the two parameters of interest, and then making one of them dependent on the other. An alternative Statistical approach requires knowledge of the degree of correlation between the two parameters (in terms of a correlation coefficient) and a sampling method capable of dealing with correlated distributions. It is not just parameters for which there are correlations however; for example, processes such as precipitation and erosion are also linked and could also be investigated.

One approach to addressing correlation issues is to use measured data from a site, which is the approach taken by SKB. However, if using published data there are various considerations that must be taken into account such as soil texture and other variables that can be used to partition data.

It was suggested that it may be useful to share information on significant correlations and methods for addressing those correlations, Such correlations could relate to parameters associated with biosphere system modelling and/or radionuclide behaviour in those systems.

Further comments or suggestions are invited on whether and how to take the suggestion forward.

5.4 REDUCING UNCERTAINTIES IN RISK ASSESSMENTS

Karen Smith presented on behalf of Tom Hinton (IRSN).

This proposal is about reducing uncertainties in wildlife risk assessments for non-human biota by linking sub-lethal effects from chronic radiation exposures to field dosimetry, based on a case study in the wolves of Chernobyl exclusion zone (CEZ). To establish environmental protection criteria, it is essential to accurately determine the dose received by wildlife under realistic exposure conditions so that dose-effect relationships can be developed. Current wildlife dose models, and associated field measurements, do not assess wildlife exposure realistically because they do not consider the spatial and temporal variability in habitat use, or the large heterogeneity in levels of contamination. This leads to increased uncertainty in environmental risk analyses.

The proposed work builds on and is in collaboration with novel field dosimetry research being funded by IRSN to develop a new tool by integrating two existing technologies Global Positioning Systems and Electronic Dosimetry. This tool permits an animal's location and short-term integrated dose to be periodically sent, via satellite, to the investigator.The GPS-dosimetry tool will, for the first time, clearly quantify the spatial and temporal variation in radiation levels that wild, free-ranging animals are exposed to in areas surrounding nuclear accidents such as the CEZ, where the technique is due to be applied by attaching collars to wolves. Funding from IRSN, however, is not sufficient to allow researchers to go the next crucial step and explore radiation effects as a function of the improved dosimetry. A significant opportunity now exists to expand the field-dosimetry research funded by IRSN and use state-of-the-art effect assays on the same wolves to which the new GPS-dosimetry collars will be attached.

The proposed research will support: trapping of 12 wolves; 3 wolves from 3 areas within the Belarus portion of Chernobyl's 30-km zone that differ in contaminant density (high, medium and low levels), and 3 wolves from a control area in Belarus (Naliboki Forest); and collection of biological samples (hair, tooth enamel, blood samples, parasites, etc.) to meet 4 objectives that will quantify the relationships between radiation dose and sub-lethal effects:

a) Evaluate sub-lethal health effects by quantifying parasite loads, altered blood chemistry, immunosuppression parameters, and prevalence of infectious diseases

b) Evaluate epigenetic effects by quantifying the relationship between whole genome levels of methylation and radiation exposure

c) Quantify effects of radiation exposure on gene expression using a functional genomics approach that will identify the up- or down-regulation of genes associated with specific physiological pathways (e.g., reproduction, immune function, oxidative stress, DNA damage, disease)

d) Evaluate telomeric lengths and cytogenetic effects. (The length of telomeres can serve as an integrative, cumulative biomarker of radiation exposure).

The proposed work will provide important data to support the evaluation of confidence the dose rate at which harm becomes probable, as well as assist in resolving discussion of the some 50 scientific articles published by Moller and Mousseau on Chernobyl, over the last 10 years, which document negative effects at dose rates previously thought not to be damaging to populations of organisms, i.e. at dose rates that are two orders of magnitude lower than what the current paradigms in radioecology would predict[c].

5.5 PLANNING FOR 2014

The 2014 BIOPROTA annual workshop will be hosted by NDA-RWMD in London. The date of the workshop provisionally planned to be held in May. BIOPROTA members will be canvassed for the most convenient particular date. The May meeting could, if convenient, be held back to back with another workshop, with the topic for the workshop identified from the results on-going projects (Section 2) or as a part of the work programme of possible new projects.

The work of Ray Kowe (NDA-RWMD) in chairing the BIOPROTA SC in 2012/13 is gratefully acknowledged. Ray Kowe has kindly agreed to continue to chair the SC for the coming year.

[c] As reported in Garnier-Laplace, et al. 2013 JENR 121:12-21

Nominations for a new chairperson will be invited in December 2013, prior to the new chair taking up their responsibilities at the end of the meeting in May 2014.

APPENDIX A. LIST OF PARTICIPANTS

Participant	Affiliation
Sandi Viršek	ARAO, Slovenia
Bojan Hertl	ARAO, Slovenia
Palona Tavcar	SNSA, Slovenia
Lydia Morche	BfS, Germany
Danyl Perez-Sanchez	Ciemat, Spain
Karen Smith	RadEcol Consulting Ltd, UK
Elsa Vitorge	EdF, France
Jurgen Hansmann	ENSI, Switzerland
Markus Hugi	ENSI, Switzerland
Stuart Walker	EPA, USA
Andrew Sowder	EPRI, USA
Koen Mannaerts	FANC, Belgium
Graham Smith	GMS Abingdon Ltd, UK
Valerie Nicoulaud	IRSN, France
Takashi Nakamura	Janus, Japan
Takashi Inoue	JGC Corporation, Japan
Mike Thorne	Mike Thorne and Associates, UK
Sven Keesman	Nagra, Switzerland
Ali Hosseini	NRPA, Norway
Takao Ohi	NUMO, Japan
Neale Hunt	NWMO, Canada
Ari Ikonen	Posiva, Finland
Thomas Hjerpe	Facilia, Sweden
Ville Kangasniemi	Pyhäjärvi Institute, Finland
Anne-Maj Lahdenperä	Saanio & Riekkola Oy, Finland
Lasse Aro	Finnish Forest Research Institute , Finland
Ray Kowe	NDA-RWMD, UK
Trevor Sumerling	SAM (for LLWR), UK
Talal al Mahaini	SCK·CEN, Belgium
Jordi Vives	SCK·CEN, Belgium
Eva Andersson	SKB, Sweden
Ulrik Kautsky	SKB, Sweden
Sara Norden	SKB, Sweden
Shulan Xu	SSM, Sweden
Bjorn Dverstorp	SSM, Sweden
Laura Limer	LimerSC (for SSM), China