BIOPROTA

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

Report of the Fourteenth BIOPROTA Workshop

Nancy, France
21-24 May 2012

Version 2.0, Final
August 2012

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 ANDRA and EDF in Nancy, France from 21-24 May 2012. The workshop marked 10 years of BIOPROTA activities.

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

Version History

Version 1.0: Draft report prepared by Karen Smith and Graham Smith (BIOPROTA Technical Secretariat) and distributed 5 July 2012 to workshop participants for comment.

Version 2.0: Final report prepared by Karen Smith and Graham Smith (BIOPROTA Technical Secretariat) to take account of comments received from workshop participants. Distributed 10 August 2012.

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1. INTRODUCTION

The fourteenth BIOPROTA workshop, which marks 10 years of BIOPROTA activities, was hosted by ANDRA and EDF in Nancy, France from 21 to 24 May 2012. To mark 10 years of BIOPROTA activities, an extended workshop was arranged, which included a field trip to the Meuse/Haute-Marne Environmental Observatory (OPE), and a greater focus on scientific presentations on biosphere issues and programmes of relevance to long-term assessments of radioactivity in the environment.

The support of ANDRA in the organisation and hosting of the workshop is gratefully acknowledged. The additional support of EDF in the organisation of the meeting and sponsoring of the workshop dinner is also gratefully acknowledged. The objectives of the workshop were:

- to briefly update interested parties on progress since the last meeting in June 2011 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;
- to provide an opportunity to learn from the Andra approach to monitoring and preserving biosphere information through the OPE;
- to discuss the future strategic direction of the BIOPROTA collaborative forum; 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 Yves Thiry (Andra) and Patrick Landais (Research & Development Director at Andra) who also provided an introduction to the OPE. This and other presentations are summarised and discussed in Section 3. This was followed by a presentation from Simon Norris (NDA-RWMD), the current BIOPROTA chairman, previewing the achievements of BIOPROTA over the years and implications for the next steps.

Simon began by observing that the BIOPROTA forum was initiated in 2002, following a workshop hosted by Andra in Paris. The objective of the forum was to support resolution of key issues in biosphere assessments for contaminant releases associated with radioactive waste disposal. Participation of the forum is aimed at national authorities, agencies and other organisations, including technical support organisations and independent research institutions, with responsibilities and interests related to achieving safe and acceptable radioactive waste management. In 2002 there were 8 member organisations. This has increased currently to 21 sponsoring members and 2 non-funding academic members:

- Andra, France
- ARAO, Slovenia
- AREVA, France
- BfS, Germany
- LLWR, UK
- Nagra, Switzerland
- NDA (RWMD), UK
- NRPA, Norway

- CIEMAT, Spain
- EdF, France
- EPRI, USA
- ENSI, Switzerland
- IRSN, France
- JGC Corporation, Japan
- KAERI, Korea
- NUMO, Japan
- NWMO, Canada
- Posiva, Finland
- SCK.CEN, Belgium
- SKB, Sweden
- SSM, Sweden
- Norwegian University of Life Sciences (UMB), Norway; and
- Oregon State University (OSU), USA.

A key strength to BIOPROTA is the collaborative and open working mechanism. Annual workshops are designed to promote the sharing of knowledge among member organisations and their technical support organisations. Challenging issues relating to the science supporting various assessments are identified and where those issues are found to be of common interest, the discussion forms the basis for the development of work programmes (projects and/or specialist workshops) to address those issues via shared allocation of technical and financial resources from interested organisations. A list of BIOPROTA technical reports is included as Appendix A.

Membership to date has been focussed towards those organisations with an interest safe disposal of radioactive waste. However, it is recognised that those working in other fields such as nuclear site restoration, mine and ore processing sites and the management of land contaminated with pernicious long-lived trace contaminants share similar assessment issues. As such, extending the remit (and participation) into these areas may increase the sharing of knowledge arising from practical experience in site-specific investigation, characterisation and assessments between radioactive waste, and other hazardous and mixed waste management communities.

1.1 WORKSHOP PARTICIPATION

The current workshop was attended by 47 participants from 14 countries, representing a range of operators, national regulatory authorities, technical support organisations and academic researchers. Participants are listed in Appendix B.

1.2 REPORT STRUCTURE

The remainder of this report is structured to provide:

- An overview of progress made in 2011/12 (Section 2);
- A summary of presentations made by participants on their biosphere programmes, including challenges faced (Section 3);
- An overview of parallel working groups (Section 4);
- A summary of interest areas that could form the forward programme (Section 5); and,
- Administrative issues (Section 6).

2. PROGRESS IN 2011/12 OF ESTABLISHED BIOPROTA WORK PROGRAMMES

2.1 DEMONSTRATING COMPLIANCE WITH PROTECTION OBJECTIVES FOR NON-HUMAN BIOTA DOSE ASSESSMENTS

Mike Wood presented.

Recent recommendations from the ICRP have incorporated biodiversity as a protection goal in terms of the release of radioactivity to the environment, implying that any planned release should be demonstrated to have an acceptably low impact on the maintenance of biodiversity. However, ICRP provide no guidance as to how to put this protection objective into practice, particularly in terms of demonstrating compliance. Although a range of assessment approaches has been developed, these are often associated with an initial screening value (or values), but these values vary nationally and, at present, there is no international consensus about what the value should be in terms or the level of protection afforded by any such level. In addition to variability in numerical screening values, no upper benchmark has been set. As such, there may be a tendency to apply what are intended as screening values as limits. Even where such interpretation is not applied to assessments, there can be difficulty in placing assessments in the context of level of harm implied where screening values are exceeded due to the lack of secondary (higher) numerical benchmarks.

In the absence of international guidance, BIOPROTA established a project with the overall aim of facilitating the application of environmental protection objectives, specifically in terms of assessments for geological disposal facilities for radioactive waste. There were two key questions associated asked within the project:

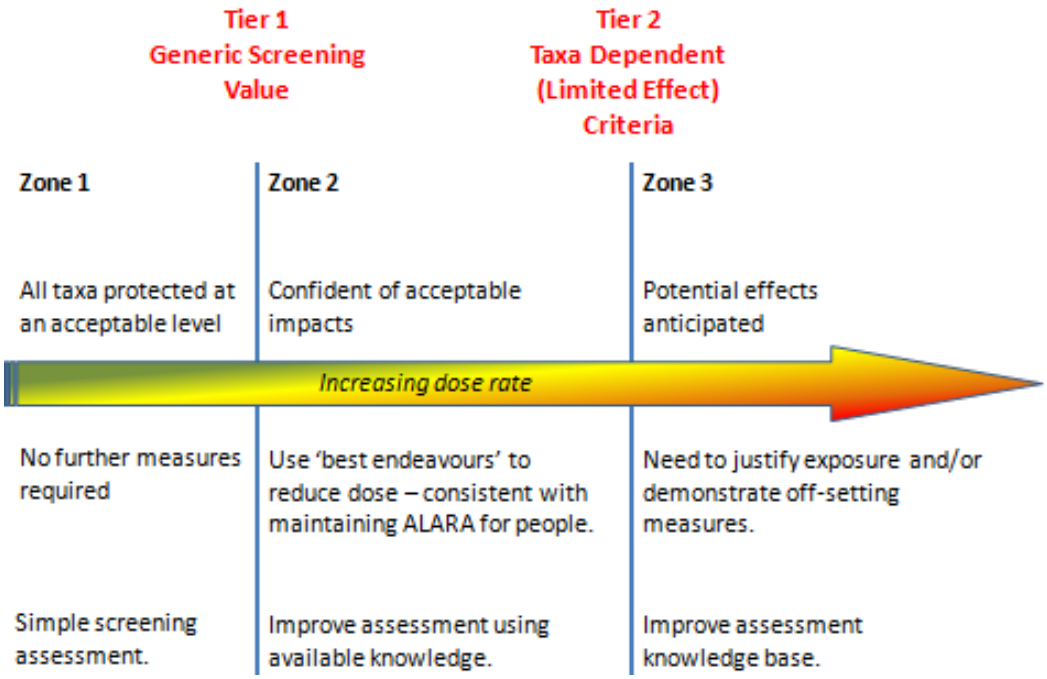
- What we are trying to protect (i.e. what would be and appropriate focal point in terms of demonstrating negligible impact on biodiversity)?
- How can adequate protection be demonstrated?

A further objective of the project was to encourage, and contribute to, international debate of the issue.

The project began in 2011 and the project report was finalised in March 2012.

In terms of the focus of protection, biodiversity can be considered in a number of ways ranging from the number of species present to the variation in genes within a species. To focus on genes as a protection objective would imply protection at the level of an individual, which is not only impractical, but would be more stringent than the level of protection applied to chemical pollutants in the environment. The alternative extreme is to focus on species; however, this implies that local populations would be expendable, which is not only contrary to some national protection objectives, but is also unlikely to pass public scrutiny. As such, populations of species would be a pragmatic focal point for demonstrating environmental protection.

In terms of demonstrating protection, a two-tier, three-zone framework was proposed as indicated in the following figure.



Whilst options for deriving generic screening and taxa-dependent (limited effect) numerical values were discussed, it was acknowledged that the supporting effects database is a limiting factor in their application. As such the view of project participants was, as an interim and pragmatic approach, to adopt the ERICA and UNSCEAR benchmark values as tier 1 and tier 2 assessment criteria respectively. The upper value of the ICRP derived consideration reference levels were considered an additional source of tier 2 values, allowing greater delineation between effects on different groups of plants and animals.

In discussions it was noted that SCK·CEN have also recently looked at environmental protection criteria and concluded that populations and ecosystems should be focussed upon for which both population effects data and ecosystem modelling would be required. However, radioecologists have been wary of applying ecosystem models in the past and this is an area of interest for the forward IAEA MODARIA biota task group as well as STAR Network of Excellence in Radioecology.

The ability to incorporate chemotoxic effects within the framework was also discussed. Multiple stressors is an area of increasing interest internationally; however, the ability to predict interactions among different stressors would be a significant complicating factor.

2.2 REFERENCE APPROAPCH FOR HUMAN INTRUSION EVENTS INTO DEEP GEOLOGICAL DISPOSAL FACILITIES

Graham Smith presented.

This project is focused on why and how human intrusion (HI) may occur in a deep geological facility (defined as disposal at greater than 50m), and how this could lead to radiation exposure to those involved. The need to address this issue is explicit in international recommendations, but unlike the case for near-surface disposal, there is no international guidance on how to address it. The objective

of the project was therefore to offer suggestions on a reference approach to address HI in post-closure safety assessments, bearing in mind that such suggestions must be flexible enough to be interpretable in the light of national regulatory requirements and facility settings.

The intrusion mechanism focussed upon was drilling and geological investigation. Simple 'stylised' models were applied to assess doses to drill workers and others studying the core material according to how they interact with material brought to the surface under different drilling conditions. A workshop, hosted by SSM in Sweden, was held to discuss and review the approach proposed. Here it was also decided to also consider the doses to others using the site, who might be exposed to contamination left at the site after drilling activities have ceased.

Different waste types, geological environments and engineered barrier systems were considered so that the method should be applicable to many different sites and deep disposal conditions.

Doses have been calculated on the basis of unit activity concentration of each of a range of relevant radionuclides, for unit exposure time and unit contaminated core length. A total of 58 combinations of drill techniques and geological materials have been evaluated. These normalised results can be scaled according to waste inventories assessed to be present in wastes, near field or wider geosphere materials at the time of drilling.

It was proposed that exposure and doses resulting from material left at the surface should be based on existing approaches applied for the clearance of contaminated land. This would avoid the creation of yet another assessment for circumstances which have already been scrutinised in great detail, as well as providing a consistent assessment basis for present day and future. The approach was illustrated with quantitative examples, which suggest that doses to those involved in drilling and geological investigation would tend to get higher or similar doses compared to those using the site afterwards.

Illustrations of the application of the approach have been provided based on realistic inventories for intrusion into high level and intermediate level radioactive waste.

Data for the models were selected on a cautious but realistic basis. All the parameter assumptions have been laid out so that alternative assumptions can be readily considered.

The project report has been sent to project sponsors for comment and approval for wider distribution. An MS Excel workbook has also been produced that provides the normalised dose results and data for the 58 different drilling scenarios and geologies.

POSIVA has provisionally agreed to publish the report in its technical report series.

2.3 SE-79 IN THE SOIL-PLANT SYSTEM: APPROACHES TO MODELLING

Graham Smith presented.

Phase 1 was undertaken in 2010. This looked to identify behaviour issues in soils and plants, to undertake a FEP (features, events and processes) analysis, and to develop an interaction matrix of the relevant FEPs. Phase 2 was established in 2011 involving the application of different models of varied levels of complexity to a set scenario. The principle objective was to explore differences in models and data assumptions in order to consider whether more complex models help address uncertainties in the representation of Se-79 behaviour in soils and uptake into plants.

Aside from conventional model approaches (applying Kd and CR values to represent partitioning between soil solids and liquid phases and uptake from soil liquid phase into plants, respectively), three more process-orientated Se-79 specific model approaches were applied:

- CIEMAT model which considers the behaviour of Se-79 over a soil profile, with behaviour varying according to changes in soil moisture conditions (as a substitute for redox conditions). Plant uptake occurs via roots with root distribution varying with soil layer and soil moisture conditions. Cycling of plant material back to soil organic matter is included and loss from the system by volatilisation and plant evapotranspiration are considered.

- Andra SAMM model which is similarly complex to that developed for CIEMAT with multiple soil layers being represented, plant root distribution varying with soil layer depth and the ability to consider organic matter cycling and loss from volatilisation/ evapotranspiration included.

- IRSN E-K model, which applies a different approach whereby the kinetics of exchange between labile and recalcitrant selenium are taken into account.

Whilst results indicate wide variation in soil Se-79 activity concentrations between these models, plant activity concentrations are reassuringly similar (within a factor of 2 when plant cropping is taken into account) suggesting that the use of these more process-orientated models, whether or not they include volatilisation, may serve to (justifiably) reduce the importance of Se-79 in repository safety assessments. Nonetheless, there may be merit in applying the different approaches to a real scenario where both soil and plant activity concentrations are known, to evaluate further the predictive capabilities of the different approaches. Such data may arise from sites to which agronomic biofortification practices are applied, such as in Finland, for which soil monitoring may be routine. However, the requirement to continually add selenium to soils suggests continued loss from the system. This may arise from methylation and subsequent volatilisation of the added selenium. Alternatively, labile selenium may be lost via surface water run-off. The final draft Se-79 report has been finalised and distributed, after the workshop, and is due to be published within the ANDRA external report series.

2.4 C-14 LONG-TERM DOSE ASSESSMENT (PHASE 2)

Graham Smith presented.

There is considerable interest in C-14 with work first being published on this radionuclide by BIOPROTA in 2005. Since this time, two further phases of work have been undertaken. The first considered the FEPs relevant to C-14 release from soils and uptake into plants and the construction of an interaction matrix to represent the linkages between these FEPs. Phase 2 then comprised a model intercomparison exercise.

Five models were applied to a hypothetical scenario which assumed that C-14 is released as methane and converted to carbon dioxide by microbial activity in surface soils. Carbon dioxide is then released from soils and is available for foliar uptake by crops.

Variability in model results was large; however, when the C-14 concentration in the plant canopy atmosphere was fixed, variability was significantly reduced. Uncertainty in models is therefore focussed around plant canopy atmosphere dynamics.

The final report on Phase 2 was completed and distributed in February 2012. SSM have also kindly agreed to publish the final report in their reports series. A further phase of work is being proposed to address remaining uncertainties in the modelling of C-14 in soils, including review of further research and model development work on uptake into plants, but also incorporating C-14 behaviour in freshwater ecosystems. Information on the proposed forward work programme is provided in Section 6.2.

2.5 MODELLING THE U-238 DECAY SERIES

Graham Smith presented.

Many organisations have an interest in the long-term radiological impacts of U-238 series radionuclides, which may be released from radioactive waste disposal facilities. The half-life of U-238 is much longer than the stability of near-surface environments and the likely period of effectiveness of engineered and natural barriers in shallow and deep disposal facilities. Particular interest arises because of the very wide range of half-lives of the radionuclides in the series, and the degree of disequilibrium which may arise over different temporal and spatial scales.

The U-238 project has focussed on the upper section (U-238 to Ra-226) of the decay series, and migration and accumulation in soils. The exercise has not been to identify the most applicable model. This would depend on the details of the assessment context. Rather, the objective has been to exchange information on how to address the complex range of relevant processes.

Project output has included:

- Development of an interaction matrix that details linkages between key features and processes affecting the migration of the radionuclides of interest, U-238, U-234, Th-230 and Ra-226, in surface soils and in crops.
- The description of a range of assessment models.
- The development and modelling of two scenarios for geosphere to biosphere release, for a hypothetical site, and an actual site in Spain, Los Ratones, with information provided by CIEMAT. Quantitative estimates of the U-238, U-234, Th-230 and Ra-226 concentrations in specific components soil and plants were made.
- The presentation of results to allow similarities and differences in the different modelling approaches used to evaluate the scenarios.

Two types of models were included in the study:

- conventional radionuclide transfer models with one or two soil compartments, which consider simplistic dynamics of the radionuclides within a soil profile; and
- more complex models that have the potential to account for changes in redox conditions throughout a soil profile (discretised into more than 2 layers), and the effect of redox conditions upon radionuclide behaviour (e.g. sorption and uptake).

The hypothetical scenario was used to explore the significance of competing processes of infiltration and capillary rise. The more complex models are better able to represent this. For the Los Ratones site, results ranged over about factor 75, which matches natural variation seen in the environment.

However, the exercise demonstrated the difficulty of characterising a site well enough to allow assessment of long-term radiological impacts.

The project report has been sent to project sponsors for comment and approval for wider distribution..

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 POSIVA BIOSPHERE ASSESSMENT

Ari Ikonen and Thomas Hjerpe presented.

In Finland there are two nuclear sites that together provide a large fraction of the country's energy.

The licence application for the construction of a geological repository at Olkiluoto, the island hosting the largest of the two nuclear sites, is due to be submitted in December 2012. Six years later, the application for the operational licence will be submitted.

The reference design is KBS-3V (vertical emplacement of spent fuel canisters) with an alternative KBS-3H (horizontal emplacement) being considered as a variant. The repository footprint covers much of Olkiluoto Island and will be sufficient for the 6,000 canisters of spent fuel considered in the licence submission: extension of the facility will be required in line with future nuclear build in the country.

Within the safety case, the surface environment is considered as an active part of the disposal system, but serves no safety function. The timeframe for the dose assessment is set by the Finnish regulator, STUK, as 'several millennia', which has been interpreted by Posiva as 10,000 years (post-closure). However, whilst this is the period of focus for the modelling of dose impacts, additional criteria are applied in a stylised approach to timeframes post-10,000 years.

A particular feature of the Finnish assessment is the rate of post-glacial land uplift (at present around 6 mm/y) which must be taken into account in the assessment, resulting in the formation of new land areas throughout the assessment timeframe. This biosphere evolution is rapid compared with radionuclide release rates and is considered as a dynamic process in the biosphere model. Future land rise modelling is based on an understanding of the past evolution of the site that is then projected to the future.

STUK stipulate a number of requirements for the licence submission and supporting safety case, as interpreted by Posiva:

- Information and data must be presented clearly and be transparent and traceable, whilst reporting must remain brief;
- High quality scientific knowledge must be applied, but alternative research and data should not be omitted;
- A comprehensive set of scenarios must be considered; and,

- A cautious approach is to be employed such that impact is not underestimated, yet excessive conservatism must not be employed such that results should not be unduly pessimistic (the amount of conservatism must therefore be reasonably quantified). The BIOPROTA forum was noted to serve as a good tool in this regard by providing a mechanism by which the relative scale of conservatism may be evaluated.

Whilst the most realistic repository evolution scenario is that no canisters will be defective within the repository and, as such, radionuclide migration will be prevented throughout the assessment timeframe, there is a Government Decree that stipulates that the base scenario (i.e. "the most expected") must consider there is some defect leading to radionuclide release.

Within the biosphere assessment, the following questions are being addressed:

- How does the biosphere evolve over the assessment timeframe, taking into account land uplift?
- How do radionuclides migrate and accumulate within the biosphere?
- How do humans interact with their environment and, hence, gain exposure to radioactivity?
- How do plants and animals become exposed within the environment, including land use?

These questions will be addressed in a series of biosphere-related reports within the overall safety assessment. Modelling of the biosphere is considered to be at least as large a task as the rest of the modelling capability for the repository.

Draft results were presented.

Around 25 scenarios have been evaluated within land uplift and subsequent ecosystem development modelling and a matrix developed in terms of landscape evolution and the drivers behind this. The matrix will be used to bound uncertainty in landscape evolution: it is not intended that all 25 scenarios will be evaluated in detail in the full dose assessment.

In the reference case, discharge areas coincide with agricultural areas close to a river. However, in a variant case where no agriculture is assumed, all discharges are to forest. In the case of more rapid land uplift with maximum agricultural use, discharges are again to agricultural areas. The difference between this latter scenario and the reference case is that smaller lakes are anticipated to form as compared with the reference case and the terrestrial areas emerge from the sea within a shorter timescale. Releases are assumed to occur from around 3,000 years post-closure.

A screening evaluation has been undertaken to identify those radionuclides that have little if any impact on dose. This helps focus activities on those radionuclides for which good assessment data are justifiably required. In terms of geosphere modelling of the reference case, 11 key radionuclides have been identified, but for the biosphere modelling this is reduced to 5: Ag-108m, C-14, Cl-36, I-129 and Mo-93.

Within the biosphere landscape model, biosphere objects (forest, agriculture, lakes, rivers etc.) are represented as compartments that are interlinked. Each object is subdivided into biotopes to take account of the different environmental properties such as photic and aphotic water regions etc.

Human intrusion (drilling) scenarios have been considered, including a direct canister hit, a near miss (penetrating clay buffer) with return of drilling core to the surface, and drilling into the tunnel back-fill. The BIOPROTA reference approach described in Section 2 was used. Clay buffer and tunnel back-fill contamination is assumed to occur as a result of a pin-hole defect in a canister. In the case of the tunnel back-fill scenario, mobile radionuclides contribute to dose whereas the more immobile radionuclides are the focus in the clay buffer scenario. The dose associated with the clay buffer is around 3 orders of magnitude greater than that associated with the tunnel back-fill scenario, but the likelihood is much lower (it is assumed that only one canister is defective within the repository). For the scenario whereby drilling directly penetrates a canister in the immediate years post-closure, very high doses are predicted with americium and plutonium contributing largely to calculated doses. Calculated doses decrease with time, for example 28 Sv at 1,000 years post-closure, reducing to 1 Sv at 100,000 years post-closure. C-14, Cl-36 and I-129 are the most important radionuclides for the assessment. However, recently control rods have been included within the waste inventory such that Ag-108m is also important.

3.2 THE ARAO WASTE DISPOSAL PROGRAMME

Sandi Viršek presented.

ARAO radioactive waste management activities are currently focussed on a low and intermediate level waste (L/ILW) disposal project in Slovenia. The country has four nuclear facilities, including a uranium mine, a research reactor, a central interim storage facility and a nuclear power plant which is jointly owned with Croatia. All waste from the power plant is stored in Slovenia, along with waste generated by small users. The current waste store is 95% full and, as such, a decision has been made to construct a disposal facility. Tailings from the uranium mine will also require treatment at some stage.

Slovenia itself covers an area of some 20,000 km^2 and has a population of around 2 million. Much of the country comprises the Alps and around a third of the country is designated as Natura 2000 protected sites. As such, finding a location for a disposal facility is difficult, particularly since public acceptance for the location is a requirement. This can have an important influence on the siting of the facility since it can result in less technically ideal disposal areas.

The site selection procedure began in 2004 with communities being invited to offer municipalities for the disposal facility. Eight responses were received. A screening programme was subsequently undertaken that looked at site geology, hydrological conditions and environmental protection areas. Areas in the immediate vicinity of municipalities or on municipality borders were excluded. In 2006 one site remained out of the initial eight.

Following the development of three alternative design concepts for the facility, near surface disposal was accepted by the Government as the disposal strategy for the Vrbina – Krško site, which is located in the vicinity of the river Sava. Groundwater in the area is at a depth of between 4 and 5 metres from the surface. This will result in the disposal facility being situated within the saturation zone below an aquifer. Waste containers will placed in concrete containers that will then be emplaced within the disposal silo. In order to avoid hydrological pressure, consideration is being given to artificially hydrating the facility, which would avoid the need for a drainage gallery under the silo. However, public opinion is in favour of such a gallery.

There is a fault zone on the eastern border of the site, which is believed to be inactive with investigations underway to confirm this.

It is planned that a permit for the design and construction of the facility will be granted by 2016 with construction being completed by 2019.

3.3 THE ENSI PROGRAMME

Manuel Sentis and Lara Duro presented.

ENSI is the Swiss federal nuclear safety inspectorate which has a regulatory mission to:

- review licence applications and to supervise changes in nuclear installations, inclusive of nuclear power plants, research facilities, research reactors and interim storage facilities;
- supervise the safety of the public from radiation and the transport of radioactive material; and
- to assess proposed solutions for geological disposal of radioactive waste, including the review of the safety assessment of Nagra (the organisation responsible for the implementation of the geological disposal programme in Switzerland).

The site selection process for a geological disposal facility is based around a sectorial plan. The facility development will be regulated on the basis of Swiss land use legislation, requiring that the site selection process is both transparent and fair and involves local stakeholders. Whilst safety is the top priority, socio-economics and land-use planning aspects are also important considerations in the process.

Within the process, ENSI has a general responsibility for undertaking the safety review, for defining safety criteria and for independently reviewing proposed sites with respect to safety and technical feasibility. The safety criteria are detailed in the table below. ENSI also provides both scientific and technical knowledge to authorities, stakeholders and the public and leads the Technical Forum on Safety.

Safety Criteria for the Site Selection Process	
1. Properties of the host rock and geological formations contributing to waste islolation	1.1 Spatial extent 1.2 Hydraulic barrier effect 1.3 Geochemical conditions 1.4 Release pathways
2. Long-term stability	2.1 Stability of site and rock properties 2.2 Erosion 2.3 Repository-induced influences 2.4 Conflicts of use
3. Reliability of geological information	3.1 Ease of rock characterization 3.2 Explorability of spatial conditions 3.3 Predictability of long-term changes
4. Engineering Suitability	4.1 Rock mechanical properties 4.2 Underground access

In the case of low and intermediate level waste (L/ILW) there are currently six sites under consideration whereas for the disposal of high level waste (HLW), three sites are currently within the site selection process. The three sites being considered for HLW disposal are consistent with three of those being considered for L/ILW disposal. It is anticipated that the commissioning of a facility for L/ILW disposal could occur from 2030 and for HLW, commissioning of a disposal facility is likely from 2040.

In terms of modelling, the focus to date has been on modelling the inventory, transport to the geosphere, hydro-mechanical and chemical coupling and the effects of gas generation, which is particularly relevant for clay rocks, which characterise many of the sites being considered. Results of modelling undertaken independently by both Nagra and ENSI have been compared and results are reassuringly similar.

Whilst biosphere modelling has not been a key focus of modelling efforts to date, there is a move to developing capabilities in this area, with Amphos 21 assisting in this field. The developed capacity in biosphere modelling will be applied to future phases of the repository siting process. The objective at present is to verify biosphere dose conversion factors (BDCF) for a selection of safety-relevant radionuclides from Nagra's 'Opalinus Clay' project (Nagra report: NTB 02-05) through the application of different tools. Amber is being used as the code for model validation.

The Opalinus Clay reference case was based around six compartments (topsoil, deep soil, local aquifer, surface water, bed sediment and sink) with three mechanisms for radionuclide transport, comprising advective transport, diffusive transport and adhesion onto solid material (i.e. solid material fluxes). The activity concentrations in the top soil, the local aquifer and in surface water are the most important in terms of dose modelling. The BDCF's are calculated on the basis of the following equation:

$$BDCF\left({}^{Sv}/_{Bq}\right) = \frac{Steady-state\ annual\ dose\ \left({}^{Sv}/_{y}\right)}{Input\ value\ \left({}^{Bq}/_{y}\right)}$$

Results of the BDCF calculations performed in Amber were within 10% of those calculated by Nagra. The greatest BDCF was calculated for Th-230 whereas the lowest was for Po-210. Ingestion was the most important dose pathway in all cases, contributing around 99% to human dose for 9 out of the 12 radionuclides analysed.

Non-metallic elements all had low sorption coefficients (Kd) and, hence, dose pathways influenced by the transfer of radionuclides in the liquid phase were dominant (90% of dose was associated with the consumption of meat and milk). Metallic elements however were associated with higher Kd values resulting in soil contamination pathways being more important to dose. Solid mass transfer processes were important in influencing BDCFs for metallic elements.

The study concluded that the application of alternative modelling codes is useful for model validation. The forward work programme will include review of the conceptual model, transfer processes and parameter databases. Divergence from the Nagra approach to modelling may occur in the future; however, having reproduced the results of Nagra using an alternative modelling approach has been a valuable exercise in ensuring and demonstrating model understanding.

3.4 THE KAERI PROGRAMME

Jongtae Jeong presented.

There are currently 21 nuclear power plants (NPP) in operation in Korea across four sites. A further 7 plants are under construction and 4 more are planned. A facility for the disposal of L/ILW is under construction (delays, partly attributed to the site characterisation programme, have postponed the completion which was anticipated in 2009 with the first disposals of L/ILW due to take place in 2010). Waste is currently stored at an in interim storage facility associated with one of the NPP sites. The policy for the disposal of spent fuel is to be decided upon in consultation with the public. Currently spent fuel is stored on site and this will continue until at least 2016.

The Korean Act for radiation management has been effective since 2009 with its entry into force leading the way for the formation of the radioactive waste management corporation (KRMC), the responsible body for overseeing the national policy for radioactive waste management. A fund was also established which is to be paid by the generators of radioactive waste. KRMC is responsible for managing the fund. In addition, KMRC is responsible for overseeing the transport and disposal of L/ILW; interim storage and disposal of spent fuel; the siting, construction and operation of radioactive waste management facilities; and for research and development relating to radioactive waste disposal and spent fuel management.

Research and development activities for high level waste (HLW) disposal are focussed on the pyro-processing of spent nuclear fuel from pressurised water reactors (PWR). This process has the potential to give rise to fuel for CANDU (sodium-cooled fast reactors) and greatly reduces disposal space requirements (by a factor of 100). Korea and the US have started a 10 year feasibility study on pyro-processing. Spent fuel from PWR plants would be subject to interim storage followed by pyro-processing; giving rise to new fuel for CANDU reactors plus a smaller volume of waste then being sent for disposal. Additional advantages of pyro-processing include a reduction in the overall management period for spent fuel and an increase in the utilisation of uranium sourced from the spent fuel.

Research and development activities for HLW disposal have also focussed on the development of an advanced Korean reference disposal system (A-KRS) which aims to integrate all future HLW with LLW disposal. There are a number of research topics associated with this programme, including system development, safety assessment of the disposal system, demonstration of the performance of the engineered barrier system and site characterisation studies focussed on the geo-environment (including tectonics, groundwater movement and in situ hydraulic tests).

The KAERI underground research tunnel (KURT) completed constructed in 2006, enabling situ experiments to be performed such as solute migration studies, borehole heater tests and hydrogeological and geochemical investigations. The facility, which has an access tunnel of 180m in length and two research modules, has been adopted as a candidate partner facility for their underground research facility (URF) network. An expansion to the facility is due to be completed in 2013 which will allow more intensive experiments to be performed and will provide an additional research module.

Further research and development activities are focussed on long-term safety assessment for HLW disposal. A safety assessment tool has been developed for A-KRS, based on the KURT environment, using Goldsim. The exposure groups considered are farmers, freshwater fishermen and marine fishermen. A FEP analysis has been undertaken and one reference and four alternative scenarios have been developed. These are being used to evaluate regulatory compliance and, from the results to date, the acceptability of design feasibility has been demonstrated. Probabilistic long-term assessments have been performed using the tool and sensitivity and uncertainty analyses

undertaken. The programme, which will run until March 2017, is intended to support the development of the safety case and will include consideration of complimentary safety indicators. The safety case will be subject to international peer review.

3.5 PROPORTIONATE APPROACH TO BIOSPHERE ASSESSMENT AND TREATMENT OF UNCERTAINTIES AT LLWR

Trevor Sumerling presented.

The LLW Repository (LLWR) in the UK requires a permit to be granted for disposals to continue at the facility; failure to obtain such a permit would have a large impact on the UK strategy for radioactive waste. As such, in May 2011 an environmental safety case (ESC) was submitted to the Environment Agency (the licensing authority for England and Wales) and LLWR is currently responding to comments received to date. Once comments have been addressed, the permit application will be submitted.

The LLWR has a volumetric capacity sufficient to accept all LLW in the UK radioactive waste inventory up until 2031. By this date, the facility will have been operational for 170 years, over which time the regulatory regime has developed considerably.

The site is located close to Sellafield on the Cumbrian coast, which is subject to coastal erosion. It is a predominantly rural area and a protected habitat is located to the west of the site (and protected species are known to be transient between the protected habitat and the LLWR site).

The ESC was prepared in consideration of the 2009 Guidance on Requirements for Authorisation (GRA) for near surface solid radioactive waste disposal facilities and active dialogue between the site and the Environment Agency. Whilst coastal erosion is an important feature of the coastal environment around LLWR, the Environment Agency has stated that, so long as the conditions stipulated in the GRA are met, then the risk of disruption from coastal erosion in the future is acceptable. The Environment Agency has also stated that the preference is for a realistic safety assessment to be performed due to conservative constraints being applied. However, this is not entirely feasible due in part to the long-term nature of the assessment; the approach taken is therefore to consider what is broadly expected to happen at the site and to apply cautiously realistic models and data. The level of effort applied to address uncertainties in the assessment is proportionate with the potential impact.

Key issues identified over recent years that are being addressed include:

- Risks from C-14 bearing gas are high and remain above the risk guidance level for 300 years post-emplacement whereas it is aimed that site control will be relinquished after 100 years. Work is therefore on-going to reduce conservativeness associated with the C-14 biosphere model.

- Radon average dose rates in the UK are 1 mSv/y and many homes have radon levels above the action level of 200 Bq/m^3 (equivalent to 10 mSv/y). The dose rate guideline level applied to the site is 3 mSv/y and disposed waste contains greater activity concentrations of Ra-226 than occur naturally around the UK. Well-based regressions have been used to link radon in soils to that in homes and what would be expected to occur in homes as a result of activity concentrations in soil/spoil. A waste emplacement strategy has been adopted which is consistent with the regulatory guidance levels.

- Coastal erosion is affecting the cliff near the site and the rate of erosion will increase in line with sea rise which could lead to erosion of the facility in somewhere between a few hundred and a few thousand years' time. Doses associated with erosion of the facility have been estimated based on understanding of the processes occurring (developed from surveys, radar and mapping of the area and projecting models based on the historical development of the site to future scenarios. Doses to potentially exposed groups (local recreational beach user, marine foodstuff consumers and coastal occupational beach user) have been assessed and risks are consistent with regulatory guidance.

- Due to the long operational period of the facility, different wastes have been disposed of in different ways such that there is a large heterogeneity of waste in terms of form and activity throughout the site. As such, the activities disposed of vary considerably between disposal trenches and the degree of organic material associated with waste also varies. Large-scale heterogeneity has therefore been included in all models, including those for the near-field within the 2011 ESC. Nonetheless, the Environment Agency has requested that small-scale heterogeneity, i.e. at the particulate scale, be evaluated. Cautious estimates of the potential for higher activity radioactive particulate materials within wastes at LLWR have therefore been made. The UK Health Protection Agency methodology (and habit data) as applied to assessment of Sellafield beach particles have been applied. Results indicated that 1 particle per tonne of sand may occur, based on highly conservative assumptions, for most radionuclides. No deterministic effects would occur as a result of the particles and the effective doses would be less than 100 mSv for particles that might be encountered, but in the order of µSv for those that would be likely to be encountered. All risks were less than 10^{-6} per year.

The forward biosphere work programme is to continue to address comments raised on the 2011 ESC by the Environment Agency, including looking at releases during the period of authorisation and to address those areas required in support of the permit application and development of waste acceptance criteria. This will include further assessment of C-14 arising from the facility and consideration of non-radioactive waste materials, including asbestos. Environmental and coastal monitoring will continue as ongoing tasks and scientific developments, e.g. with regard to climate and sea-level forecasts and erosion modelling will continue to be followed.

3.6 ENRESA & CIEMAT RESEARCH PROGRAMME FOR RADIOACTIVE WASTE DISPOSAL

Danyl Perez-Sanchez presented.

There are eight nuclear power plants in Spain plus a disposal facility for L/ILW and VLLW at El Cabril. This facility has been operational since 1992. Most radioactive waste (more than 70%) is generated by the power plants (both from operational and decommissioning activities), although both hospitals and research facilities also contribute. Based on current nuclear power capacity in Spain and an operating lifetime of 40 years for nuclear power plants, the amount of radioactive waste to be managed is estimated at 176,300 m^3 of L/ILW and 12,800 m^3 of HLW.

In the case of L/ILW, conditioning processes are performed at El Cabril for those wastes arising from sources other than nuclear power plants prior to being placed in a temporary storage facility. Wastes from the nuclear power plants arrive conditioned. Wastes are stored in two platform areas (north and south). Waste drums are placed in concrete containers and are immobilised through the injection of mortar. The compact block is then placed in the disposal cell, which is a structure of reinforced

concrete. Once the disposal cell is filled with 320 containers, the upper reinforced concrete closure slab is constructed and weatherproofed. A seepage control network is in place to avoid leakage to the biosphere. This network also allows monitoring of discharges from the facility and hence, the evaluation of the continuing condition of waste packages. A 300 year site surveillance and control period is in place. In the case of VLLW, the controls are not so vital and concrete is not used as a barrier but more to maintain waste form under storage conditions. Topsoil is used to cover the disposal area and a control period of 60 years is in place.

The Spanish government position on HLW is for centralised temporary storage with research focussing around generic long-term storage. There is a clear distinction between interim and final solutions for HLW in recognition of the need for further analysis of long-term options. A centralised facility will be located in the southeast with waste stored in vitrified form.

ENRESA has a research and development plan which aims to increase understanding in the field of radioactive waste disposal and the evolution of technology at an international level and to develop in-house capacities and infrastructure. In line with this plan, CIEMAT has an agreed research programme. The current programme runs from 2012 to 2015.

Research activities relating to El Cabril include projects relating directly to the management of LILW & VLLW at the facility, including studying covering layers, the performance of concrete, metallic and clay-based materials for barriers and the monitoring of site structures and confinement system.

Additional research activities are focussed on restoration and decontamination technologies, improvement of measurements of environmental parameters and development of hydrological models that will be used to support the safety case once a decision on HLW disposal is made. CIEMAT are specifically looking to update the safety assessment methodology for the biosphere in the storage radioactive waste at El Cabril and to improve biosphere assessment models, specifically for U-series and redox-sensitive radionuclides and to include spatially distribution modelling.

In addition to radioactive waste arising from nuclear power plants, there are also issues in Spain around phosphogypsum NORM waste arising from the fertiliser industry, particularly in relation to whether this should be treated as radioactive waste or conventional waste. Radium-226 is the main radionuclide of concern arising from the phosphogypsum industry, but Po-210 and Pb-210 are also of concern. Toxic chemicals are also present and these must also be taken into account, particularly in relation to the application of phosphogypsum to agricultural land. The international approach to dealing with such wastes is therefore being reviewed. In moving forward, sensitivities around the implications of regulatory controls will be considered to ensure that the industry does not move from Spain to other less-regulated countries. The overall intention is to harmonise radiological assessments such that NORM wastes are included: biosphere models are therefore being applied to different NORM scenarios to evaluate their applicability.

Although not currently required under Spanish regulations, there is an awareness that non-human biota assessments are likely to be a requirement in the future and knowledge in this area is therefore developing. The ultimate objective is to develop a screening tool that would be relevant to both NORM and radioactive waste storage and be applicable to human dose assessments and non-human biota. Work is on-going between CIEMAT and other international groups in this area. There is also interest in developing assessment methodologies such that radioactive and toxic wastes (e.g. as arising from mercury mines) could be integrated. Work is therefore on-going to compile information on laws and

regulations and to review methods for the management and remediation of areas contaminated with radioactivity and toxic materials.

3.7 THE SKB PROGRAMME

Ulrik Kautsky presented.

SKB is the Swedish organisation with responsibility for the disposal of radioactive waste, including that arising from industrial and medical facilities. Over recent years the primary focus has been upon the disposal of spent nuclear fuel and a licence submission was made last year for the construction of a deep geological disposal facility at Forsmark. It is intended that the Forsmark facility will be operational from 2025 to 2070. The safety assessment undertaken in support of the licence submission indicates that doses will be well below the regulatory risk limit and even further below the risk level corresponding to background radiation in Sweden. The licence submission is currently under review by the Swedish regulator, SSM, by OECD-NEA experts and SSM consultants. Responses from the review are due in June 2012. The decision on the licence submission is not expected for another 2 to 3 years.

Current work is therefore largely focussed on the disposal of lower activity wastes within two disposal facilities, SFR which is an operational facility for the disposal of LLW and SFL for intermediate long-lived waste for which disposal concepts are developing. Further details on the SFR assessment, which is due late in 2013, are provided in Section 3.8.

For both facilities, climate in the shorter term (the first few 10,000 years) is of interest as compared against the period of interest for the Forsmark facility. Climate predictions, based on work undertaken within the SR-Site project are currently being worked into scientific papers for a special issue of Ambio journal on 'The Future Climate, Landscape And Ecosystems And Its Application For Safety Assessments Of Radioactive Waste'. The special issue is intended to contain between 10 and 14 specialised papers and will be published in May 2013.

One of the key radionuclides in the assessment from Forsmark is Cl-36. Work is therefore continuing to address remaining uncertainties associated with modelling the behaviour of this radionuclide through learning from others in the field (for example through information exchange within the BIOPROTA community) but also by considering stable chlorine behaviour. Other interest areas include molybdenum for which process information is required and methane. The assessment model is being revisited, particularly with regard to the atmospheric compartment and the treatment of C-14 dynamics for which current assumptions are conservative, giving rise to high doses from this radionuclide. Further model developments will be based on a good process understanding of C-14 behaviour. Consideration is being given as to whether the current assessment modelling software, PANDORA, should be further developed or whether an alternative model platform would be preferable. [Posiva is in similar situation regarding PANDORA].

SKB are also continuing work within their Greenland project, described further in Section 4.10, which aims to provide assessment data for an analogue colder climate. There is also interest in looking at analogue warmer climates although no sites have as yet been selected. Warmer climate conditions would be associated with higher precipitation and a more productive system than at present.

A 3 year research and development programme proposal is due to be submitted in September 2013.

3.8 SKB'S ASSESSMENT ON LOW-LEVEL AND INTERMEDIATE-LEVEL WASTE

Eva Andersson presented.

A facility, SFR, for LLW is Sweden is currently operational. It was constructed in the 1980's at a depth of 50m with waste, derived from nuclear power plants but also hospitals, being disposed of in steel or concrete containers in order to retard rather than prevent radionuclide migration. An updated safety assessment of the facility is due to be submitted in 2013. This coincides with an aspiration to extend the facility with construction extending to 100 m depth, which will provide waste disposal facilities consistent with the greater operational period of Swedish nuclear power plants and will allow decommissioning waste to be disposed of. The layout of the extension has not yet been finalised.

The safety assessment for the facility, including the planned extension, is focussed on an assessment period of 100,000 years. A regulatory risk limit of 10^{-6} (equivalent to a dose of around 14 µSv) is in place for the human dose assessment. A biota dose assessment is also required.

A model is available for the assessment; however this requires revisions to take account of comments received on the last safety assessment submissions and to update in line with new knowledge and to address key areas of uncertainty. A particular area of focus will be on C-14 since current doses calculated for people are very close to the dose limit particularly during the lake climate/land-transition phase, based on the current facility and excluding the proposed extension. Conservatisms therefore need to be addressed within the model if a permit to extend the facility is to be achieved: previously, it was assumed that all methane entering the atmospheric compartment is retained with no loss from the system whereas for organic forms in lakes, it was assumed that people derive all their diet from the consumption of fish. The behaviour of C-14 in the radionuclide transport model is therefore a key focus area for development in support of the 2013 safety assessment.

The last assessment focussed on one large lake being formed as land uplift occurs whereas for the current assessment also smaller objects will be considered. Model resolution is also being focussed upon, particularly in relation to whether current resolution is appropriate for evaluating how radionuclides migrate on both spatial and temporal scales. The transition between landscape objects is also an important consideration for radionuclide transport. Whether annual means as parameter inputs are appropriate or whether these should move to seasonal data are also being investigated. Investigations to date suggest that annual averages are indeed sufficient.

Whilst there is an overall objective in biosphere modelling at SKB to move away from K_d and CR transfer parameters for radionuclides, this will not be possible within the assessment timeframe for the SFR safety assessment. As such, work is underway to update these transfer parameters for the top ten radionuclides (C-14, Cl-36, Mo-93, Cs-135, Ni-59, Se-79, Nb-94, Tc-99, Ag-108m and I-129).

Human behaviour assumptions are also being revised. One factor that will differ from SR-Site is that, in addition to considering the number of individuals that can be sustained within a biosphere object, also realistic considerations around cohabitation requirements of people, i.e. families and communities will be taken into account. Appropriate limitations around human use of the biosphere and diets will also be considered (i.e. an individual will not obtain all dietary carbon from consumption of fish). Three key human lifestyles being focused upon: hunter-gatherer, early agriculture where wetlands are not utilised and modern agriculture where wetland areas (potentially radionuclide hotspots) are drained for agricultural use.

The SFR safety assessment is due to be submitted at the end of 2013.

4. RADIOACTIVE WASTE MANAGEMENT AND BIOSPHERE ASSESSMENT: SCIENTIFIC PRESENTATIONS

4.1 OBJECTIVES AND SCOPE OF THE MEUSE/HAUTE-MARNE ENVIRONMENTAL OBSERVATORY

Patrick Landais presented.

As part of the process for licensing a deep repository for radioactive waste, Planning Act of 2006, ANDRA is required to carry out an environmental impact evaluation including providing the reference state of the environment corresponding with the size, impact and duration of the disposal project (CIGEO). As a result, the Observatoire Pérenne de l'Environnement (OPE), an operational and scientific tool for environmental monitoring, emerged in 2007 with different specific ambitions:

- a 100 years long project,
- a multi-disciplinary (ecosystem) approach for both observation and sampling (allowing the control of different environmental factors),
- a large spatial scale (several watersheds),
- the traceability of the data,
- the preservation of the samples, and
- a link between observations, R&D and biosphere transfer models for safety assessment.

The specific industrial and operational objectives include:

- Establish a representative initial state of the site and its environment before Cigeo construction
- Establish environmental and socioeconomic criteria in order to facilitate the selection of the zones on which the surface facilities will be installed
- Contribute to the definition of the potential environmental compensatory measures
- Prepare the future environmental monitoring program of the industrial site
- Identify and explain the origin of any disturbance of the environment or the presence of pollutants from the beginning of the construction

The scientific objectives include:

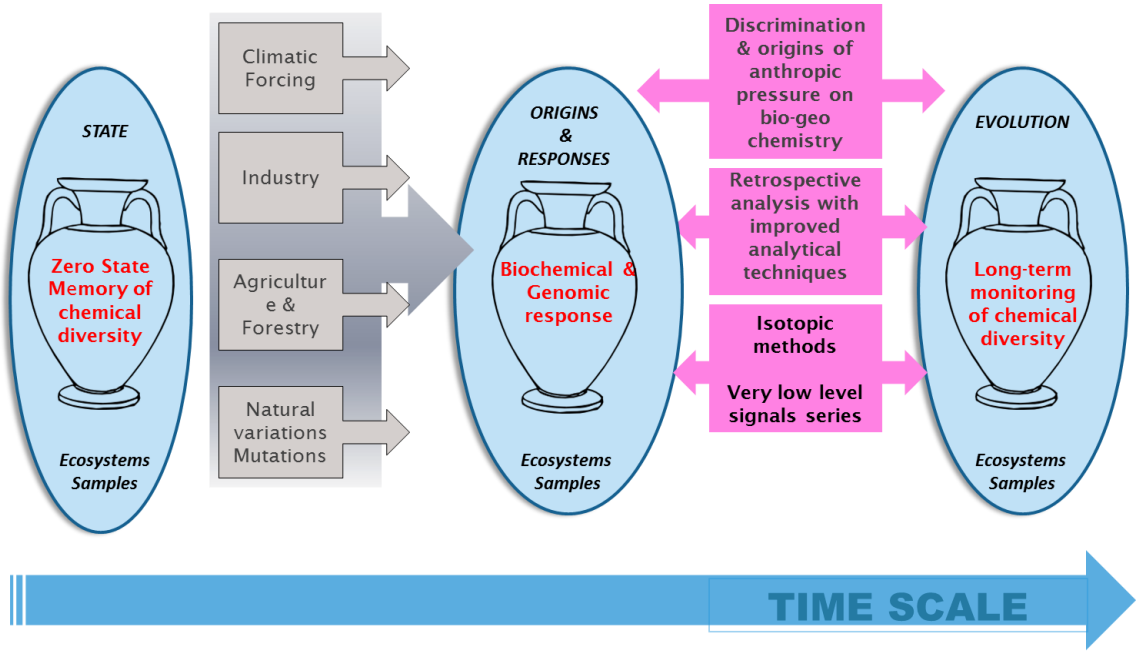
- Integrate the diversity of the ecosystems (forest, meadow, culture, aquatic) and their interactions into a single observation program,

- Use the organized instrumentation and the data acquired as a base for an ambitious scientific and metrological program: comparison of three ecosystems (evolution, biogeochemical cycles, biodiversity), definition and development of indicators and environmental sensors
- Use the data to understand and anticipate the interactions between the different media and the evolution of their quality, to identify the causes of the observed evolutions, to evaluate models mainly based on equilibrium between biosphere compartments

Current initiatives and tools include:

- Inventory and observations network (for 100 y.): flora, fauna, agricultural productions, physicochemical and biological quality of soils and waters, meteorological data (about 85 000 data/y. ; 500 measurement points)
- Monitoring of forestry and agricultural practices;
- Radiological and geochemical background
- Image, data and measurement from satellite and airborne remote detection (SPOT images, ortho-photo, Lidar, radar, …);
- Storage of the data in a database coupled with a geographical Information system (220 000 data) ;
- Integration of OPE into national and international networks (RMQS, Renecofor & F-ORE-T, AIRLOR, ICOS, plant, birds, …);
- Environmental specimen banking.

Mr Landais described the work on-going and planned concerning site characterisation and environmental sampling, with particular emphasis on the link between knowledge of the site and the biosphere part of the safety assessment, and the need for long-term storage of samples, the significance of which may not yet already be apparent. This process is illustrated in the following figure.



As part of the workshop, Elisabeth Leclerc organised an excellent, very interesting visit for participants to the OPE, in order to see and explain on the spot the wide variety of monitoring activities on-going, for air, water and soils. The visit was very well appreciated by all participants.

4.2 POSIVA MONITORING PROGRAMME FOR THE REPOSITORY CONSTRUCTION PHASE

Jani Helin presented.

The aims of the Olkiluoto monitoring programme, which began in 2003, are to make continuous or periodic observations and measurements of engineering, environmental and/or radiological parameters to support the evaluation of the behaviour of components of the repository system and the impacts of repository construction and operation on the environment. The programme is also designed to help in making decisions on the implementation of successive phases of the disposal concept. Hourly, weekly and more periodic sampling is undertaken. The monitoring requirements are determined largely from government and regulatory requirements, but some aspects of the programme have been incorporated to meet municipality requirements. The programme includes engineered barriers, rock mechanics, hydrology, hydrogeochemistry, foreign materials and the surface environment.

The monitoring programme objectives are set out for the period 2004 to 2011 in Posiva Report 2003-05 with results from the programme being reported on an annual basis. An updated programme of monitoring has now been outlined for the forward period (2012-2018) and this will be detailed in Posiva Report 2012-01, which is due to be published at the end of 2012. Annual reporting of results will continue with reports being made available from the Posiva website (www.posiva.fi). Data obtained through the monitoring programme are entered into a database called POTTI.

The forward monitoring programme is divided into aspects specific to long-term safety, such as geosphere evolution; how the surface environment interacts and affects the geosphere; site characterisation and biosphere modelling input data; interactions between groundwater and the surface environment; environmental impact monitoring; and, radiological monitoring.

In terms of the evolution of the geosphere, the programme considers how rainwater infiltrates the overburden and subsequent interaction with deeper groundwater with the amount and quality of water

being evaluated. Land uplift and its impact on landscape transitions is also a focus area as the monitoring activities will continue also during the century-long operational period enabling adequate time span for this kind of follow-up.

The monitoring programme for interactions between the surface environment and groundwater in bedrock includes atmospheric conditions, surface water runoff and land use (which affects water quantity and quality). Data derived from this programme is used as input to the modelling of surface and near-surface hydrological conditions and studies on the infiltration of groundwater.

Environmental impact monitoring is focussed on the construction phase and includes dust, noise, effluent waters and vegetation cover and how this affects both people and biota on the island.

The radiological monitoring programme aims to establish a baseline against which radiological impacts associated with the operational phase of the facility can be assessed. Existence of a nuclear power plant in operation, with additional units under construction and planned, adds some challenge in the interpretation of the data, but also provides a longer time perspective (starting in the 1970s).

The site characterisation and biosphere modelling input data programme is focussed on evaluating how elements are taken up and stored by vegetation and foodweb cycling in both terrestrial and aquatic systems and in the derivation of required time-series data. The programme includes the overburden, i.e. soils and sediments, and focuses on the key elements for dose assessments (people and biota), which have been selected through a screening evaluation of a preliminary set of repository assessment cases.

A biotope classification system has been established based on the fertility of the overburden and, for aquatic systems, the ability for plants to attach to substrates and biota to dwell within sediments combined with photic conditions. In the terrestrial environment, intensive sampling plots have been established on the island, which allow continuous and expansive monitoring. This network of sampling plots is supplemented with data derived from periodic sampling programmes which may occur only every few years. Monitoring sites have also been identified for the aquatic environments around the site with the network of sites including areas around the island's nuclear power plant. The aquatic monitoring programme utilises both sampling plot areas and transects that are largely accessed by boat.

Olkiluoto Island is relatively small, which has in itself led to some difficulties in establishing a permanent monitoring network since much of the land area is utilised by the nuclear power plants, roads, power lines, dwellings and the repository construction site (about 30% of the 12 km² but widely distributed). A nature conservation site (0.6 km²) is also present which places further restrictions on the land area available for monitoring.

The monitoring programme of Posiva is supplemented by that conducted by the nuclear power plant, which focuses on the aquatic environment due to the main impact being the discharge of cooling waters. The Finnish Forest Research Institute is also conducting research on the forest ecosystems around Finland which provides additional data from similarly designed, constructed and operated monitoring plots. Wherever possible, monitoring campaigns are integrated such that samples are obtained that will provide multiple data in support of the overall assessment programme.

4.3 ENVIRONMENTAL SAMPLE BANKS

Elisabeth Leclerc presented.

The setting up of an environmental sample bank is linked to the OPE discussed in section 4.1. The French geological disposal facility is due to begin construction in 2017 (pending submission and approval of the construction licence). The sampling programme began in 2007 and therefore there will be 10 years of data from which baseline conditions can be established prior to construction. The preservation of these samples allows for analyses to be replicated and for new analyses to be undertaken in the future, for example in line with developing analysis methods and future assessment requirements. Sampling and banking of samples will then continue for some years after thus enabling the evolution of the environment to be evaluated.

The sample bank is aimed at surface environment samples, with a particular bias to the agricultural inland zone around the repository site. Forests are also included. Samples taken for banking are representative of the environment and, in the case of agricultural systems, include food chain pathways such as cheese, eggs and vegetable garden produce plus more general samples that can be used to characterise the environment such as lichens, soil and soil-percolated water plus indicator organisms such as worms. River and subsurface water samples are also taken; however it is difficult to preserve water samples over a long period and, as such additional samples from the aquatic environment are obtained, including mosses and invertebrates such as mussels. Endangered species plus old specimens will also be banked.

The establishment of environmental sample banks is not restricted to nuclear energy aims and objectives: such banks have already been established in many countries such as the USA and Germany, Japan and Sweden. Sample banks have also been established in different areas of France, however these are restricted to dry storage techniques. The ANDRA sample bank will use three forms of sample storage – dry (e.g. sieved soils for major element and routine analysis), deep freeze (for unprocessed 'raw' samples such as soil, bones and water that are required for more specific analysis such as soil structure) and cryogeny, which can be used for samples that will be subject to ultra-trace element analysis. Clean room conditions are thus required for cryogenically preserved samples with samples being stored above the level of liquid nitrogen to prevent interaction between nitrogen and the samples.

The sample bank being constructed will be sufficient for up to 600 kg of dry samples per year, 140 kg of deep frozen and 180 kg of cryogenically preserved samples per year. Over 20 years, this equates to 12,000 kg of dry samples, 2,800 kg of deep frozen and 3,600 kg of cryogenically preserved samples. The facility, which is currently under construction, can be expanded in the future if required. The facility will be operational by March 2013.

In addition to preserving samples in support of establishing a baseline for the French repository, the sample bank will also be used for a number of scientific programmes and will provide the opportunity for human health monitoring to be undertaken, for example through fluid and tissue banking. By preserving samples for the future, retrospective analyses will be possible for elements and contaminants not currently monitored – for example in line with new environmental and public health protection directives for substances not yet recognised as important in terms of human and environmental health. Biodiversity banking may also be possible with DNA being cryogenically preserved.

It is considered that the facility will be unique in being constructed to meet both industrial and scientific objectives and through sampling both food chain and natural samples from a variety of different systems. The facility will be made available to the international community and forms part of the international network of environmental sample banks (www.inter-esb.com).

4.4 DETERMINATION OF SITE-SPECIFIC KD FOR FRESHWATERS

Laura Marang presented.

EdF is currently responsible for running 500 dams, 19 nuclear power plants plus some fossil fuel power stations, both of which require cooling water, and are also developing hydropower technologies for the marine ecosystem – a national hydraulic and environmental laboratory has been created to support development in this field. The hydraulic and environmental laboratory forms one of 15 EdF Research and Development divisions and has a mission to increase realism of impact assessments, improve knowledge on the fate of pollutants. There are two primary objectives:

- To consolidate the environmental acceptability of EdF production facilities in relation to the aquatic environment (and health via the food chain) including thermal, chemical, radiological and biological discharges and their impact on factors such as the continuity of water courses.
- To protect the production facilities (dams, nuclear sites) against environmental hazards such as sea level rise, floods, storms and drought conditions.

In increasing realism in impact assessments, the division contributes to the optimisation of radioactive waste storage and disposal in France (EdF is responsible, by law, for the waste generated by their facilities and for paying for waste storage). Improvement in assessments is largely achieved through the incorporation of site-specific data with K_d being a key parameter as speciation governs the mobility and bioavailability of radionuclides. Biota dose assessments in the ERICA assessment tool rely on K_d for both marine and freshwater environments in order to derive dose estimates for aquatic biota both in terms of internal and external dose. Similarly OURSON, the human dose assessment model developed by EdF, requires K_d parameter values to predict activity concentrations in the dissolved phase that are then used to derive activity concentrations in fish and drinking water.

K_d is influenced by a range of physicochemical conditions hence there is a large variability in Kd values reported in the literature. Best estimates are not considered sufficient for modelling studies due to the range in empirical values and the preferred approach is therefore to apply probability distribution functions (PDF).

Differences are observed in available databases; for example, there are considerable differences observed between the IAEA TRS472 compilation of data and that presented in ERICA. This is in part driven by differences in approach in the derivation of data (for example whether arithmetic mean or geometric mean is presented), but also arises from methods used to address data gaps. Within ERICA a common approach has been to apply data from the marine environment to freshwater where gaps are evident. Irrespective of the differences in approach, variability would naturally occur in different water systems, driven by physicochemical properties such as pH, major cations and particulate organic carbon (POC). Parameters representative of French water bodies are therefore required in order to improve model realism and a new approach to deriving K_d has therefore been developed.

Key parameters influencing speciation have been identified and PDF's derived for each based on monitoring data for a number of French rivers derived over a 10 year period. However, in the case of POC, data were limited. Data from around the world were therefore collated and analysed. A trend was observed for all rivers between particulate organic carbon and suspended matter, which was influenced by river flow. These factors, which were available for French rivers, were therefore used to derive POC PDF's.

The derived PDF's are subject to Monte-Carlo sampling to determine multiple (10,000) water compositions that are representative of annual environmental variability. These compositions, together with calculated radionuclide concentrations, are used in the chemical speciation software ECOSAT to calculate Kd PDF's. Input to ECOSAT includes data relating to solution chemistry, humic binding, oxides and cation exchange. It is assumed that dissolved organic carbon (DOC) is represented by fulvic acid and that all oxides have the same properties as iron oxide. The calculations take into account competition between an element of interest and major ions and complexation by inorganic ligands, organic matter (POC and DOC) and oxides.

A set of generic parameters have been derived that enable the model to be used for a range of aquatic systems and a good agreement has been observed between predicted and measured speciation as reported in the literature. Overall, predicted values are lower than those in TRS472 or ERICA. K_d values derived for French waters were largely similar which is due to similarities in physico-chemical properties. Values showed good agreement with those reported in TRS472 for those elements for which a sufficient data base is available.

The approach has the advantages of reducing uncertainties in the application of K_d values to assessments, enabling site-specific characteristics to be taken into account thus reducing assessment uncertainties and enables values to be derived for elements for which minimal data are available, such as nickel and chromium. The approach could be applied to derive freshwater, soil or marine K_d values. A limiting factor however is that data are often lacking for some input parameters, particularly cations such that it can be difficult to incorporate all relevant processes.

It is intended that further work will be undertaken to validate the model, potentially including in situ measurements of Kd and required parameters to derive a comprehensive dataset.

4.5 WASTE MANAGEMENT ISSUES ARISING FROM THE FUKUSHIMA ACCIDENT

Kunihiro Nakai presented.

On March 11 2011 a magnitude 9.0 earthquake struck the coast of Japan, which is situated on the convergence of four tectonic plates. It was the largest magnitude earthquake to hit the country in the history records and triggered a large tsunami that affected 561 km^2 of land and damaged a million buildings. The nuclear power plant at Fukushima was almost entirely flooded resulting in the impairment of cooling water functionality due to power supply disruption and containment capability was impaired resulting in the release of radioactivity to the environment. The full extent of damage to the reactor buildings has not been confirmed due to the high level of radioactivity around buildings and the presence of highly active water within reactor buildings.

One hundred days after the tsunami hit, the water cooling system was re-established and both holding and processing facilities established for contaminated water at the site. Waste issues arising as a result of the incident include the site itself which is highly contaminated, the terrestrial environment which was contaminated through aerial releases and deposition and the marine environment to which some discharges occurred prior to the establishment of holding and processing facilities. Radionuclides released during the incident in the gaseous state were xenon, krypton, iodine, caesium and tellurium.

One year on from the incident, Cs-137 concentrations are still notable in soils and river water when compared against Sr-90 and Pu-238. Dose rates in the immediate vicinity of the site are >19 µSv/h and reduce with distance from the site although some hotspots occur outside the site perimeter. The

distribution of Cs-134 and Cs-137 around the site matches the dose rate map obtained. The increased caesium activity in the environment is evidenced by activity concentrations recorded in incinerated sewage sludge with activity concentrations from incineration facilities around Fukushima being around an order of magnitude greater than in Tokyo. Activity concentrations in sewage sludge from both areas are gradually decreasing.

Decontamination activities outside the nuclear power plant are underway, resulting in the generation of a large volume of low and very low level waste. Waste is being segregated according to the level of radioactivity and will be placed either in temporary storage facilities or disposed to controlled landfill. The temporary storage facilities will be constructed above ground. An impervious layer or sheet will be the grounding with waste being placed above and subsequently covered by sandbags to provide some protection from external radiation. A collection mechanism will be installed to collect leachate that will be monitored. Facilities are to be constructed in each city, town or community due to the scale of decontamination measures required and waste that will be generated. Facilities may be used for up to 3 years prior to wastes being retrieved and transferred to an interim storage facility where waste would remain for up to 30 years prior to final disposal. The siting and design process for the interim storage facility has begun with design differing according to level of contamination. Higher activity wastes will be stored below ground in an engineered barrier structure comprising reinforced concrete and an engineered cap that will be installed following waste emplacement. Lower activity wastes will be disposed of in near surface facilities that will be capped with soil. Only waste from the Fukushima prefecture would be transferred to the interim storage facility. Final disposal will be outside of the Fukushima prefecture.

Within the nuclear power site, the level of contamination and presence of fuel debris and highly contaminated sludge will be important considerations for waste management associated with decontamination activities. No decision has been made to date as to whether the reactors will be dismantled.

4.6 REPRESENTING RADIONUCLIDE UPTAKE FROM SOIL TO PLANTS: KEY CHALLENGES

Jordi Vives presented.

The biosphere impact studies unit at SCK·CEN is working on the cycling of elements in terrestrial systems and has conducted field research both in Mol and Chernobyl. A chlorine cycling model has previously been developed for forests, based on a forest monitoring campaign at the SCK•CEN experimental Forest site in Mol. A 1-dimensional water table model has been developed that looks at water transport in a vertical direction and will be coupled with the chlorine model. In a parallel development, the instrumental neutron activation analysis spectra obtained during the chlorine forest monitoring campaign are also being reanalysed as part of an MSc project to derive data on additional elements that could be used in model validation. These measurements comprise Al, Br, Ca, Cl, Cu, Dy, I, In, Mn, and V in soil (organic and mineral), tree roots, bark, wood, branches, twigs, needles, litter and understory.

Following from these programmes, a new project, ECORISK, has also recently begun under funding from the Belgian Science Policy Office (BELSPO). The project aims to design a decision support tool that will allow risks associated with long-term direct and indirect global changes on Belgian forest systems to be analysed. Part of this will involve the development of an integrated modelling approach to simulate the long-term distribution of a constant influx of groundwater contaminated with long-lived radionuclides into soil. Within the project, SCK·CEN are responsible for developing a module that looks at the mobility of pollutants with respect to water from an underground aquifer to the root zone,

in effect modelling the geosphere-biosphere interface zone. The initial step is the development of a water cycling model which will then be adapted to account for solute transport and exchange with the surrounding soil.

As the module is developing, additional requirements in terms of processes and data are being identified. For example, conceptualising the water table model has resulted in the identification of a number of key questions:

- Is there an agreed way to model the infiltration of groundwater to soil by capillarity (different modellers do this in different ways)?
- What is a realistic representation of the rhizosphere, factorising uptake from soil and soil solution by plant roots?
- What are the key processes (and equations) to represent interactions with nutrients and micronutrients?
- Given a model capable of representing the flow of water from the water table to plants via the roots, how can this be modified to account for radionuclide transport, including retardation or preferential transport, and what are the key equations?

Different models can be applied depending on whether the question is approached from a top down or bottom up approach and consideration is needed as to how the model can be appropriately simplified for long-term assessments to avoid over-complexity.

Initially, capillary rise in the model was represented by Philips equation. However, this was then altered such that the process is now represented by Newton dynamics equation which considers the kinetics of water movement. Soil is represented as a network of cylindrical tubes and soil parameters such as soil porosity, dispersivity and hydraulic conductivity are related to the structure of this network. The representation of capillary velocity in undisturbed soils appears quite accurate using this approach with capillary rise ceasing as expected under saturated soil conditions. The question was raised however as to whether treating soil as a simple continuous porous medium is reasonable?

Plant transport in the model was initially represented by a macroscopic linear root water uptake model; a simple approach that agreed with monitoring data up to a point. Improvements have been made by applying an exponential root water-uptake model that takes account of root density and rooting depth. This approach introduces of course new parameters, and it is inevitable that as the modelling becomes more realistic the addition of many new parameters can be a limiting factor in taking the model forward. When soils are waterlogged, anoxic conditions occur resulting in plant death and this is being incorporated. Consideration is being given to the representation of water movement within the plant, which is two-directional (upward transport in xylem and downward transport in phloem represented as suction and osmosis, respectively).

Although water transport into and within plants is important, this cannot be the sole focus since other factors, and in particular those affecting speciation in the soil solution which itself affects bioavailability, will be important with regards to the transport of elements. Solute transport is therefore being incorporated through the addition of a solid compartment with exchange rates to account for sorption and ion exchange processes in soils. Around the capillary fringe, two Kd values will be applied to account for differences in redox conditions (and hence speciation) in line with the approach taken in the Ciemat Se-79 model developed by Mike Thorne. Processes that remove species from

solution and retard sub-surface migration such as ion exchange are also being incorporated by means of a three-compartment box submodel (soil solution, exchangeable pool and mineral phase) for which the reaction rates can be derived from simple isotherm models to model transport involving equilibrium expressions for cationic and anionic exchange: Gapon formulation and Langumuir-Freunlich isotherms. In order to ensure an appropriate mass balance, root fixation and biomass cycling must also be considered.

The basic recipe for the conversion of a water transport model to solute transport is therefore to multiply all advective flows (in which the solute is physically transported along with water) such as infiltration, capillary transport and root uptake, by retardation factors which take into account the volumetric water content, the K_d and the chemical interactions with major elements affecting the K_d. Root uptake itself is complex but can be represented by multiplying by a bioaccumulation factor representing selective transfer between soil solution and plant roots of the radioelement in question in comparison with a significant chemical analogue (major cation or nutrient) that is taken by the plant.

Whilst sorption in the soil matrix is a complex process affected by a range of soil physicochemical properties, simplification is required due to data limitations and we trust that the two K_d's approach used in the model for selenium described in Section 4.15 will be applicable to represent anoxic conditions below the capillary fringe and oxic conditions above.

Whilst the basic approach has been established, a number of questions remain to be answered in relation to appropriately representing:

- Vegetation as a dynamic model component, taking into account potential differences associated with different plant/forest types (e.g. broad leaf trees versus pine forests).
- The lateral transport of sap and how relevant this is as a process.
- Nutrient relocation to perennial plant parts before leaves fall.
- The effectiveness of root uptake versus soil water needs to be further explored, taking account of the potential for selective root uptake. The BioRUR model by Casadesus et al. (2008)[a] offers an interesting avenue of exploration.
- The influence of bioturbation on radionuclide transport in the soil rooting zone.
- The coupling of plant uptake with the groundwater model.
- Timescales for combining plant transport and seasonal variations in soil hydrology.

The water cycling model is being developed on the basis of data obtained over a 2 year monitoring programme and the ECORISK project provides 2 years of funding to develop the model, plus an additional 2 years for integration and validation.

[a] Casadesus J, Sauras-Year T, Vallejo VR (2008) Predicting soil-to-plant transfer of radionuclides with a mechanistic model (BioRUR). Journal of Environmental Radioactivity 99 (5):864-871

4.7 ISSUES IN LONG-TERM ASSESSMENT OF URANIUM SITE REMEDIATION

Marie-Odile Gallerand presented.

All French uranium mines are closed, hence site remediation is a post-closure issue, yet the regulatory regime differs from other radionuclide contaminated sites: nuclear fuel cycle installations fall within the Basic Nuclear Installation Regulations whereas uranium mines fall within the Mining Code Regulation framework, which is however, not considered relevant for the post-closure phase. The national authorities responsible for the regulation of uranium mines are the Ministry of Environment and the Nuclear Safety Authority (ASN). ASN is also the national regulatory authority for nuclear installations.

A number of documents have been issued by the Ministry of Environment that define the fundamental concepts applicable to the final closure of uranium mill tailings disposal and the objectives and technical requirements for the long-term. In 2001, methodological documents were provided in support of these recommendations.

As required under the recommendations, a national plan for the management of radioactive materials and wastes was established and instituted by the 2006 Program Law. The plan has been implemented by Decree. The objective of the plan is to provide a framework for sustainable management and disposal of waste. The plan itself is updated every 3 years to take account of developments in management methods and needs for storage and disposal facilities.

The 2007-2009 plan focussed on the impacts of tailings disposals only and required AREVA to undertake an assessment to be submitted in 2008. The assessment looked at the geochemical behaviour of tailings, the stability of dams and calculations of the long-term impact of disposal. Of the 17 tailings disposal areas in France, eleven are enclosed by dams. The 2010-2012 programme then broadened the scope such that uranium mines in general were considered rather than just tailings. Impacts from the mines themselves were considered as were those arising from the use of waste rock that may be used for landscaping.

An expert group was established in 2005, which focussed on issues associated with a major uranium mine site. The aims of the expert group were to improve dialogue with local stakeholders, develop methodological tools for impact assessments, formulate recommendations to improve risk management and the surveillance network and to generalise the recommendations to all sites and consider the long-terms issues. The expert group recommended that the legal framework be amended so that former uranium mines are transferred to the control of national authorities rather than operators. It was acknowledged that a clear understanding of processes at sites is necessary for the appropriate development of models that can be applied to evaluate the future behaviour of the site and tailings. In the context of long-term assessments, a number of issues have been identified.

There are four types of disposal systems – open pit and dam, backfilled open pit, thalweg and dam and depression with ring dam. The cover applied to each disposal system will be an important safety consideration. It is intended that waste rock be used to cover the tailings in order to limit gamma dose rate and radon transfer. The waste rock will then be covered by topsoil and vegetation.

In order to develop site remediation strategies, measurements must be taken as input to models that are then applied to evaluate compliance with regulatory exposure limits. Background conditions are also required to be known to determine the impact of the mine and tailings as compared against background. As such, measurements are taken in the vicinity of the site where there is minimal mining

influence and where geological conditions are similar. Reference scenarios are being developed that will allow impacts to be calculated. The long-term impacts will then be evaluated by calculating environmental concentrations into the future and evaluating dose to hypothetical exposure groups. One reference scenario and five altered scenarios are envisaged that will consider the expected (natural) and altered evolution of the sites for three assessment timeframes (active surveillance, guaranteed surveillance of lower frequency and for the period when surveillance is not guaranteed). Outstanding questions in relation to long-term assessments are the evolution of tailings within the disposal systems, the stability of dams over time, radon modelling and water treatment and activity in sediments.

Tailings are thought to evolve naturally into a chemical and mineralogical form that will limit uranium and radium mobility. However further data is required to support this assumption and further charactersisation studies must therefore been undertaken. Characterisation efforts will focus on tailings that have been disposed of some 30 years ago as a means of evaluating chemical evolution over time.

The stability of the dams are also an area of concern, largely following the Fukushima accident. Work is required to revise probability of hazards.

For radon modelling, AREVA previously concluded that the total dose rate for the reference situation was less than 1 mSv/y, which increased by around a factor of ten for altered scenarios. However, the altered scenario results were not consistent with measured data from homes, being somewhat lower. As such there is a need to improve the modelling of radon emanation and transport in soils and accumulation in buildings. The revised model will be applied to different scenarios, including the construction of homes above the remediated waste piles and the use of waste rock in landscapes that are then build upon. The model will also be used to study the relevance and feasibility of reinforcing tailings covers as a means of limiting radon exposure over the long-term.

Liquid effluents from mines are treated in water treatment plants of which there are 14 throughout France, 10 of which apply classical chemical treatments to the effluents to remove uranium. Chemicals applied to treat effluents are then released to the environment. Alternative passive treatment options are therefore being researched by AREVA that would alleviate environmental impacts. Treatments being considered include bark bio-sorption, membrane filtration and the use of wetlands. Enhancing existing processes, for example through lime drains, are also being investigated. The evolution of mine water quality also needs to be evaluated to determine whether activity concentrations have reduced over time, whether further treatment is required and whether current treatments are efficient and effective, particularly since discharge limits may be lower in the future. Cost benefit studies will be undertaken to evaluate the benefits associated with the addition of chemicals to remove uranium and the costs associated with their entry into the environment.

4.8 SPECIATION, ACCUMULATION AND RECYCLING OF CHLORINE IN TERRESTRIAL ECOSYSTEMS

Yves Thiry presented.

Chlorine-36 is a radionuclide of particular interest due to it being a major potential contributor to long-term dose; it has a long half-life, high solubility and mobility in the environment, apparent low reactivity with biotics, is subject to isotopic dilution with stable chlorine in the geosphere and biosphere and is an essential element for biota.

Modelling approaches at ANDRA include traditional transfer models that consider the flux between compartments, which are represented by parameters such as K_d and CR and specific activity models that can be applied to the long-term chronic contamination of equilibrium systems assuming that Cl-36 rapidly equilibrates with, and distributes with, stable chlorine. Good knowledge on stable Cl behaviour in the biosphere is required for this latter approach.

Work is on-going to examine the level of complexity required for the models. Soil is currently excluded from the model, since inorganic chlorine was considered to be of primary importance and this does not accumulate in soils to any great extent. However, knowledge of the biogeochemistry of chlorine is limited and therefore further data is required to enable model simplifications to be justified.

In terms of cycling, chlorine has traditionally been considered as a conservative tracer and the focus has been on inorganic chlorine. However, many organo-chlorine compounds that are naturally formed have been identified and, in ecosystems with soils rich in organic matter, organic chlorine cycling is known to occur. Volatilisation is also known to occur.

Studies have been undertaken to look at the evolution of organic chlorine during the degradation of organic matter. The fraction of organic chlorine was found to increase rapidly during early decomposition of leaf litter. Chloroperoxidase has been identified as an enzyme produced by some fungi and involved in formation of reactive chlorine species which can oxidise organic matter leading to the production of organo-chlorines. Whilst abiotic processes also occur, biotic processes dominate.

Chlorination rate has been investigated as well as the difference between soil concentrations associated with three ecosystems (forest, pasture and agriculture). For each ecosystem, around 17 surface soils were sampled which varied in organic matter content. A good correlation was observed between organochlorine and total chlorine in all three ecosystem types. The percentage of organochlorine varied little with ecosystem type (range 83-89%), yet total chlorine and organochlorine concentrations were around twice that in forests compared with agricultural and grassland systems, as indicated in the table below.

Land use	$[Cl]_{total}$ (ppm)	$[Cl]_{org}$ (ppm)	$\%Cl_{org}$
Agriculture	49.7	33.5	87
Pasture	54.0	49.6	83
Forest	89.8	68.1	89

Agricultural areas had the lowest concentrations due to their high OM turnover rates, which reduces accumulation potential.

Studies have also looked at the influence of environmental factors on chlorine behaviour. The study considered different tree species under different climates (oceanic, transition, continental and mountain) with variable atmospheric deposits. Around 50 sites were selected that reflected a gradient in chlorine deposition (decreasing from west to east) and a range of soils and tree species. The influence of ocean-derived deposits was clear with respect to inorganic chlorine.

In forests, the mineral soil layer was the most important pool for organic chlorine. Humus was not important in terms of total concentration, but is important in terms of generation, acting as a bioreactor.

The large variation in chlorine content between soils indicates that environmental factors are important with natural production of organic chlorine being important in forests. At many of the forest sites an enrichment of chlorine from litterfall to humus was observed which results from the degradation of organic matter. Statistical analysis of the influence of eco-climatic parameters indicated that only chlorine content of humus was affected by climate, tree species, carbon content and soil pH. A good relationship was observed between organic matter in soil and organic chlorine in humus, leading to the conclusion that the content of organic matter in humus controls the extent of chlorination.

The residence time of organic chlorine is around five times greater than inorganic chlorine, but is lower than the residence time of organic matter as a whole.

Chlorine cycling in forests is a third area of research undertaken. The study focussed on a forest site for which a large data base on biomass dynamics is available. Chlorine distribution in soils and trees was investigated and biomass distribution and productivity used to quantify the cycling of chlorine in terms of flux. Luxury consumption of chlorine by coniferous vegetation was observed with toxicity being avoided through crown leaching. Luxury consumption did not occur in deciduous forests. It has been concluded that vegetation is a vector of intense recycling of chlorine, the forest floor serves as a bioreactor for organochlorine formation whilst soil serves as a sink for organochlorine which is associated with organic matter turnover.

The information resulting from the above studies has been used to validate a dynamic model involving inorganic as well as organic chlorine pools in soils. The model has been used to calculate the residence time of chlorine in the various forest compartments and to investigate the effect of atmospheric versus underground input to a system. In the case of underground contamination, the final percentage of organic chlorine was lower than for atmospheric input since, for the former, trees are the only possible vector for chlorine cycling and its further reaction with humus organic matter.

Further studies on Cl-36 will look at chlorination and de-halogenation processes in soil and the cycling of chlorine in agricultural areas. The interaction between chlorine and carbon cycling will also be investigated.

4.9 MIGRATION AND FATE OF $^{14}CH_4$ IN SOIL-PLANT TRACER EXPERIMENTS

Ray Kowe presented.

Carbon-14 could be released from a geological disposal facility over a timescale of several thousand years with sources including graphite and the corrosion of irradiated and reactive metals. Both carbon dioxide and methane could be generated, but only methane would be likely to be released to the biosphere due to assumed carbon dioxide retention by cementitious engineered barriers. There is limited knowledge on the fate and behaviour of methane as it is released from the geosphere to the biosphere, particularly within the soil zone. As such, a research programme is underway by the University of Nottingham and Serco with the following objectives:

- To obtain experimental data on the behaviour of $^{14}CH_4$ and $^{14}CO_2$ in the soil zone and the subsequent uptake of ^{14}C by plants through both laboratory and field experiments;

- To interpret the results of the experiments using appropriate techniques and models; and
- To develop an assessment model that can be used to calculate the concentration of ^{14}C in soils and plants.

The programme began in 2010 and is due to conclude in March 2013. Laboratory soil column experiments have been undertaken and the results used to help plan field experiments. Both disturbed (repacked sieved topsoil) and undisturbed soil columns were investigated with ^{13}C (as a surrogate for ^{14}C) being introduced at the base of the column and gas samples extracted from different points in the column and in the air space above the column for measurement.

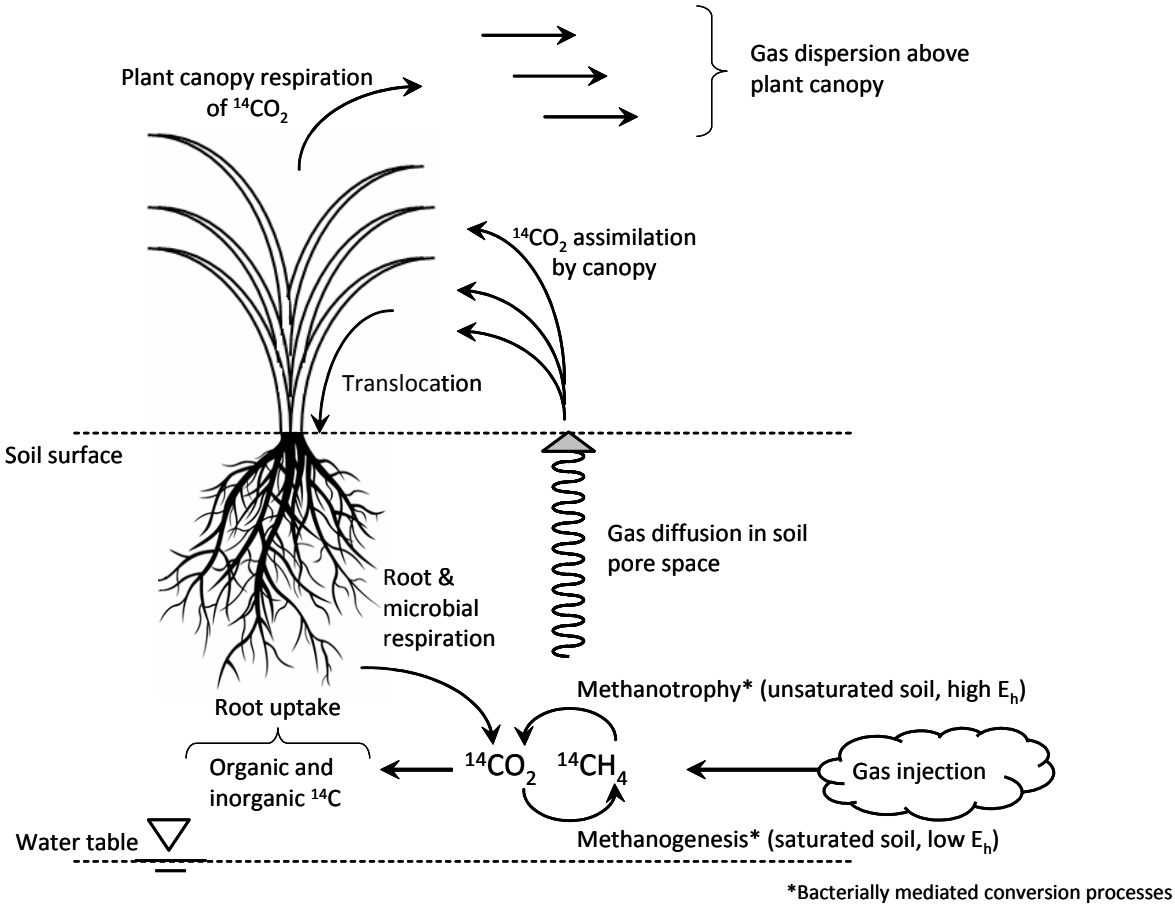
In the repacked column, methane migration was rapid (concluding within 10 hours of initial introduction) such that maximal concentrations were observed in headspace above the soil column. Migration time of methane in the undisturbed soil was longer, taking some 48 hours and overall methane concentrations throughout the column were lower than for the repacked soil.

Oxidation of methane to carbon dioxide was evident in the repacked soil with rates being much greater than for the undisturbed column; the calculated oxidation rate coefficient for repacked soils was some twenty times greater than for undisturbed soil columns. The rate coefficient for the undisturbed soil column was 0.002 h^{-1}. The differences are thought to arise as a result of the repacked column consisting of sieved topsoil which has a greater presence of microbes compared with the undisturbed subsoils.

Field experiments using rye grass have taken place at a field site near Nottingham. Wheat experiments will be carried out in summer 2012. Columns have been hammered into soil and the surrounding soil then excavated to allow sampling and injection pipes to be installed. The surrounding soil is then replaced and a headspace collector/sampler system added. Twelve columns were placed randomly in the study field for the rye grass experiments. Four columns were gassed with vegetation, four were gassed without vegetation and two sets of two columns served as controls either with or without vegetation.

Results from the rye grass experiments were consistent with the laboratory experiment findings with methane migration being observed over a period of 10 to 24 hours. Plant rooting systems were found to affect methane migration resulting in an increased rate. Atmospheric conditions were not found to influence the results. No conversion of methane to carbon dioxide was observed, but this may have been due to limited microbial activity due to dry conditions.

In order to fully interpret the results from the experiments a modelling capability is being developed. The approach is to develop a multi-component model that will incorporate both advective and diffusive transport processes and allow for the conversion of methane to carbon dioxide. Migration of gases from the soil zone to the atmosphere will be driven by meteorological conditions and uptake by plants will be via incorporation of carbon dioxide by photosynthesis. TMVOC (part of the Tough2 suite of computer programmes) is being used as the basis for model development for soil transport and this will interface with SVAT, a soil-vegetation-atmosphere transfer model, conceptually illustrated in the figure below.



Future work will include isotopic analysis of the rye grass experiment samples (soil and vegetation) to look at carbon fixation in soils through microbial activity and in plant roots and canopy. Further small scale laboratory experiments are also planned using $^{14}CH_4$ and models will be applied to both laboratory and field results.

4.10 GREENLAND ANALOGUE PROGRAMME

Ulrik Kautsky presented on behalf of Tobias Lindborg.

Two projects have been established. The Greenland Analogue Surface Project (Grasp) is focussed on Greenland as a cold climate analogue since, during permafrost conditions in the future, it is considered that people would continue to inhabit the area. A wider project, Greenland Analogue Project (GAP), is then researching the icecap and interactions with the geosphere. The latter project is being run in conjunction with Posiva and NWMO.

GRASP aims to investigate how both terrestrial and aquatic ecosystems behave under peri-glacial conditions in order to develop a conceptual understanding of surface hydrology and ecology, including the transport of elements from land to lakes and interactions with the deeper geology. This understanding will serve as the basis for identifying climate specific features and processes that are important considerations for long-term safety assessments.

Site studies include weather (precipitation and temperature), hydrological flows including lake outflow and soil moisture sampling in both frozen and non-frozen soils to investigate surface and sub-surface

water fluxes. Sampling of lake water and biota (zooplankton and fish) from the eleven reference lakes and sand and silt deposition measurements are also being undertaken.

There is a lot of various research interest in Greenland and there is therefore the potential to combine databases with other research groups.

4.11 BIOSPHERE KNOWLEDGE MANAGEMENT CONCEPT IN LONG-TERM PERFORMANCE ASSESSMENT OF GEOLOGICAL DISPOSAL

Tomoko Kato presented.

Most knowledge and experience for biosphere experts is based on 'implicit knowledge' and it is important to be able to show procedures and criteria of using the knowledge in describing the biosphere system and in the construction of biosphere models. The JAEA biosphere knowledge management concept has been developed to assist in documenting the basis for data and knowledge applied to the biosphere assessment for the post-closure phase of a geological disposal facility in Japan.

The overall aim of the management system is to identify and explain errors or omissions that may give rise to either under- or over-estimates in peak dose rates and to provide reasoned arguments for constraining assumptions for scenarios, models and parameter values.

There are two aspects to the system: the JAEA Knowledge Management Sytem (KSM) focusses on documenting the knowledge base (e.g. use of analogues, arguments and knowledge acquisition) and CoolRep which electronically stores all documents. Both are used in support of each other.

Biosphere assessment issues have been identified and recorded KSM relating to the assessment context, environmental change (including climate and human effects including those relating to human intrusion), geosphere-biosphere interface zone, water bodies and related sediments, soils, crops, foodchain, potential exposure groups and radionuclide specific information and data. Together these provide the contents of the knowledge base around biosphere modelling.

An input format has been developed that works through the issues, considers the implications, identifies what needs to be considered for biosphere modelling and suggests approaches to address the issues. Flow charts are included as appropriate to guide on the procedure and criteria for selecting site specific data and to choose realistic and reasonable combinations of conservative assumptions thus to avoid too many conservatisms that may be additive or muliplicative. Records are made to document decisions on the use of specific data or on judgements relating to the appropriateness of parameters.

The system provides a checklist of important issues for modelling and aims to avoid inconsistency and underestimation of peak dose rate. It provides a mechanism to transparently and traceably document the expert judgement process for biosphere assessments. The system also provides a good means by which decisions can be revisited in the future and understanding the reasoning behind these.

4.12 CONTRIBUTION OF THE METHYL- AND CARBOXYL-GROUP OF ACETATE TO THE ^{14}C-CONTAINING GAS PRODUCTION IN AGRICULTURAL SOILS

Nobuyoshi Ishii presented.

Transuranic waste (TRU) is generated from the reprocessing of spent fuel and mixed oxide fuel fabrication facilities. The main radionuclides contributing to dose from TRU are C-14 and I-129. However, TRU waste is categorised into four groups, one of which is characterised by the presence of hulls and end pieces for which C-14 is the key radionuclide contributing to dose.

The aims of the study were to:

1. Determine the behaviour of acetate in agricultural fields, particularly the partitioning between solid, liquid and gaseous phases; and
2. Investigate differences in the behaviour of carboxyl-^{14}C and methyl-^{14}C.

The study is based on the assumption that C-14 is transported to the biosphere in the form of acetate.

To investigate partitioning between solid, liquid and gaseous phases, 142 agricultural (paddy field and upland) soils were sampled. Soils were air dried prior to mixing with de-ionised waster and adding C-14 labelled sodium acetate. Samples were then incubated in the dark for 7 days. After 7 days, soil solution was sampled and analysed for C-14. Samples were then centrifuged and C-14 concentration in the solute also analysed and results used to calculate the quantity of C-14 in solid, liquid and gaseous phases. Of the C-14 labelled sodium acetate added to soil samples, 35% partitioned to the solid phase, 6% was in the liquid phase and 60% was released as gas. The high proportion partitioning to the solid phase is considered to result from bacterial activity (heterotrophic bacteria can incorporate C-14). Bacteria would be retained with the solid phase following centrifugation and would the activity concentration of C-14 associated with bacteria would therefore be counted within the solid phase.

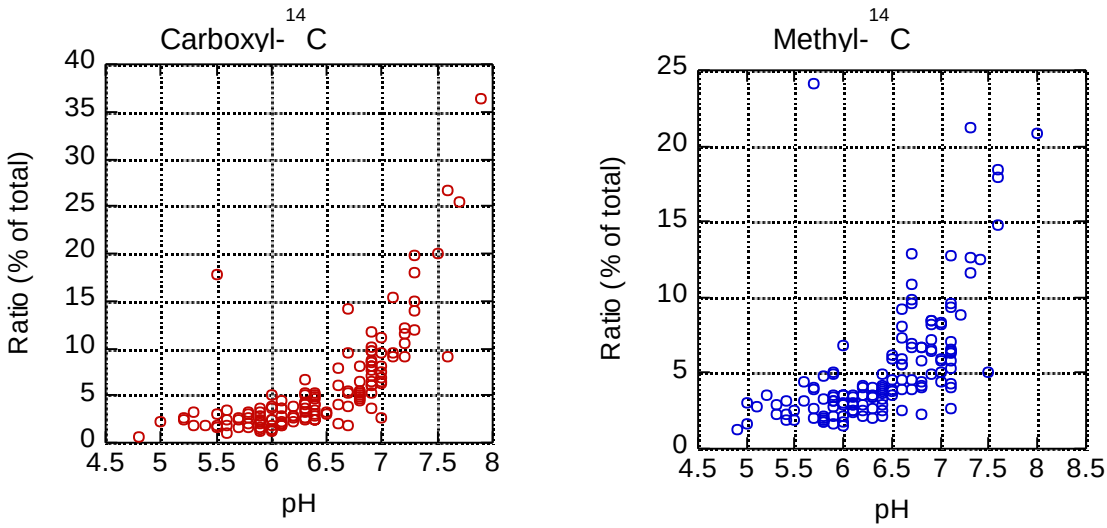
Bacterial colonies were cultured and autoradiographs clearly indicated the presence of C-14. The effect of microbial activity on partitioning between solid and liquid phases was therefore investigated. Soil samples were again subject to the same treatment as for the initial experiment; however a duplicate set of samples was run in which microbes were killed prior to the addition of C-14 labelled sodium acetate. Results indicated that, for samples with no microbial activity, 97% of C-14 was associated with the liquid phase. The partitioning to the liquid phase was found to be affected by soil pH and a good correlation was observed between C-14 partitioning to the liquid phase and total dissolved carbon dioxide.

In order to determine the dominant chemical species in gas-soil solution, a series of vials were linked to allow the transfer of gas in the headspace of one vial into subsequent vials. Nitrogen gas was added to the first vial containing the soil solution. Alkaline solution was used as a trap for carbon dioxide in subsequent vials. Results confirmed that carbon dioxide was the main C-14 gas present.

Overall results indicate that C-14 labelled sodium acetate in solution is taken up by soil microbes which assimilate around 30%. Some of the C-14 dissolves in water, depending upon the pH and the remainder (around 65%) is released to air. The dominant chemical species of C-14 gas is carbon dioxide.

Slight differences were observed in the partitioning between solid, liquid and gaseous phases between paddy and upland soil samples. These results are most likely explained by differences in microbial communities in the two soil types.

In order to investigate differences in behaviour between carboxyl and methyl groups, C-14 labelled acetic acid (which contains both groups) was employed and the partitioning between solid, liquid and gaseous phases investigated. Results indicated that the carboxyl group partitioned to the gaseous phase whereas the methyl group largely partitioned to the solid phase. Liquid phase partitioning of carboxyl and methyl groups varied according to soil moisture and pH conditions, as indicated in the following figures.



Partitioning ratios of ^{14}C into the liquid phase as a function of pH

Under aerobic conditions, carboxylic acid is broken down to give carbon dioxide, however under anaerobic conditions methane is produced. As such, although carbon dioxide was recorded under laboratory conditions, it is possible that methane would be the dominant gas produced under field conditions.

Further research is planned. Since TRU waste will persist for many years, it may be subject to climate change effects. Microbial activity is a key factor influencing behaviour and any climate changes may affect such activity. There is therefore a plan to investigate both cooling and warming effects on microbially-induced behaviour of acetate. It is envisaged that gas production would increase with temperature.

4.13 A GERMAN APPROACH TO SIMULATING EXPOSURES FROM RADIONUCLIDES POTENTIALLY RELEASED FROM A NUCLEAR WASTE REPOSITORY

4.13.1 PART 1: CONCEPTUAL FRAMEWORK

Jürgen Gerler presented.

In the development of conceptual models for reference biospheres, BfS is evaluating how the biosphere has evolved to the present day as a means of investigating the exposure scenarios and parameters that could be expected in the future. Overall there are five work packages:

1. Selection of investigation areas (reported in GRS-A-3504);
2. Analysis of current landscapes;

3. Analysis of landscapes during the quaternary (reported in GRS-A-3538);
4. Impact of future climate change on landscapes/biospheres (reported in GRS-A-3645); and
5. Preparation of conceptual models for reference biospheres.

Investigation areas have been selected both in northern and southern Germany. Selection criteria applied including presence of suitable host rock for heat generating wastes (clay or salt), availability of knowledge on the geology, hydrology and geomorphology of the area and the representativeness of the area for the surrounding region. Each of the selected areas have been classified according to characteristics such as sediment/soil type, hydrological conditions, presence of aquatic landscapes (rivers, lakes, fens and springs) and terrestrial biotopes, including wetlands. Particular differences are observed between areas in the north and south of the country.

Climate cycles have been established from the Quaternary and these cycles are expected to continue into the future. A warming of climate results in marine ingression in the north of the country whereas under colder climate conditions ice coverage is expected. Based on data for previous glacial periods, four stages of ice cover are anticipated. In total, four distinct climate states have been identified: temperate, Mediterranean, boreal and polar. The country is currently moving from a temperate to a Mediterranean climate.

In moving from a warm to a cooler climate, landscapes would be similar but organic material would accumulate. Under a much colder climate, the formation of ice would impact on the landscape, potentially resulting in erosion and/or landslides depending upon land topography and soil water content. Radionuclides in the landscape would result from existing contamination plus input from irrigation and groundwater, both of which would reduce with temperature. However, in moving from a cold to a warmer climate, organic matter degradation would occur and processes such as wind erosion and irrigation become increasingly important. Radionuclides in the landscape would result from existing contamination plus that arising from irrigation.

The analysis of processes during different climate states has provided the basis for developing conceptual models for the biosphere and representing transitions between the different climate states. Under polar conditions, transfer of radionuclides is restricted to interactions between an aquifer and rivers/wetlands.

Landscape characteristics have been identified for each biosphere model compartment and parameters determined which vary under the different climate conditions and whether areas in the north or south of Germany are considered. The parameters (e.g. precipitation, river flow rates, etc.) have been determined through site analysis.

4.13.2 PART 2: GEOCHEMISTRY OF WASTE RADIONUCLIDES IN SOILS

Volker Hormann presented.

Following landscape classification and development of the conceptual model for the biosphere, radionuclide movement through the landscape must be considered, with K_d being a particularly important parameter. A model has therefore been developed that enables K_d to be calculated under different conditions.

The model was built using the geochemical code PHREEQC, which also has the capability of carrying out exchange and complexation calculations. The model includes a number of components, including

soil solution, hydrous ferric oxide (Hfo, which has a large surface area for sorption), clay minerals (for which illite has been selected as being representative), immobile and dissolved organic matter and solid phases. Complexation models for Hfo, Illite and organic matter were taken from the literature and have been implemented in PHREEQC.

The model has been verified for uranium using published soil experiments and a good correlation is observed between modelled and measured activity concentrations. Further verification has been undertaken for caesium and again modelled results were close to experimental data. The model has therefore been applied to reference soils from the German REFESOL project. As no soil solution compositions were available for the reference soils, a standard soil solution was constructed from geometric mean values for agricultural soils with iron and aluminium concentrations being assumed as being in equilibrium with ferrihydrite and gibbsite. Phosphate fertilisation was excluded to allow comparison with literature values reported. Simulations were well within ranges reported (IAEA TRS 472) and within the vicinity of mean values for both loam and sand soils.

Key soil parameters for determining K_d are the contaminant concentration, variability in soil water content (e.g. input from precipitation or removal through evapotranspiration) which affects ionic strength, clay (mineral) content, iron and aluminium oxides, organic matter content (both immobile and dissolved), pH and redox conditions. For modelling, it is assumed that soil is saturated and no oxygen is present in solution (which corresponds to a post-rainfall or irrigation event following which microbes would have consumed available oxygen within a matter of hours).

The model has been applied to four radionuclides (caesium, nickel, selenium and uranium) that were chosen for their differences in environmental behaviour. As model substrate, one of the reference soils (stagnic luvisol) has been chosen. Concentration dependence of K_d was only observed when soil activity concentrations exceeded 100 Bq/kg (dry mass). Uranium K_d showed the greatest dependence as indicated in the figure below. No concentration dependence was observed for caesium due to competition effects.

If soil solution is diluted then the activity concentration would be expected to change. However, for the purpose of investigating dilution effects, the activity concentration was maintained in the model simulations. Dilution of soil solution resulted in an increase in K_d with the effect being most pronounced for nickel. This results from reduced ionic strength of soil solution such that competition with major ions is lower. Where evaporation from soils is simulated the K_d lowers due to an increase in competition by major ions. Again the effect was most pronounced for nickel.

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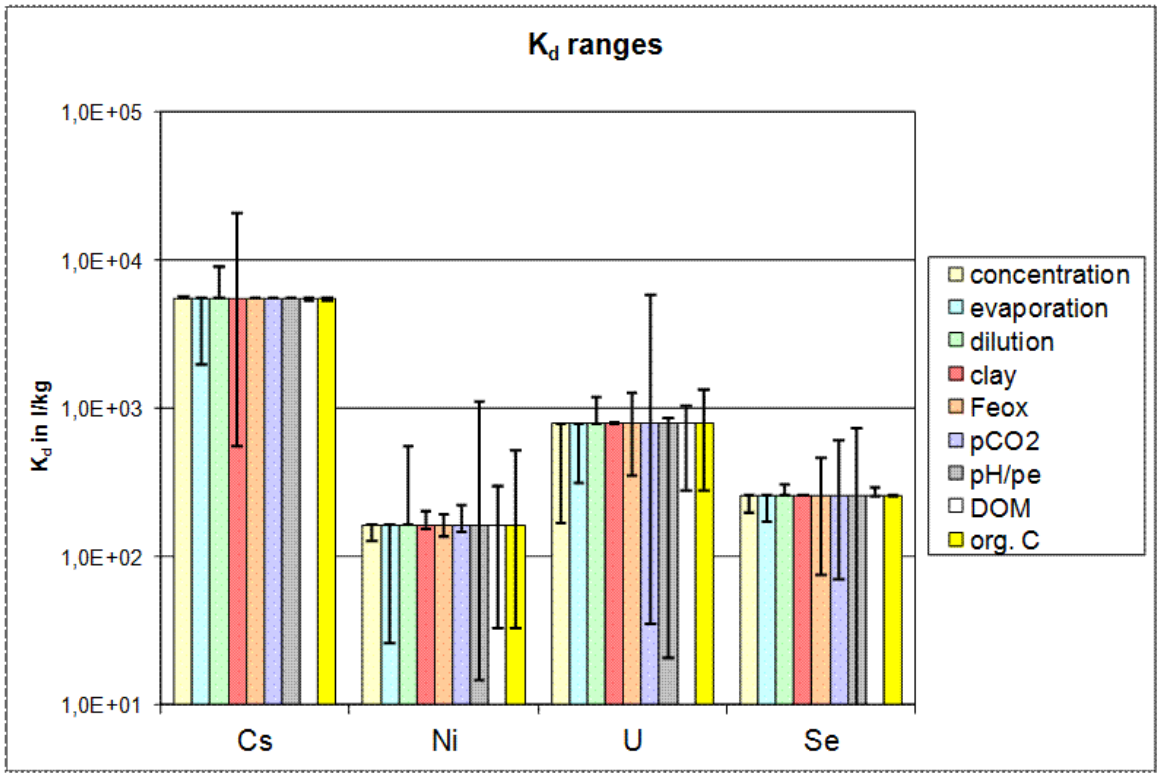


Comparison of Kd variability for all soil parameters (the whiskers denote the minimum-maximum ranges)

If the clay content of soil is varied, the effect on K_d is most evident for caesium due to changes in availability of binding sites. Only a slight dependency on clay content was observed for nickel and a negligible influence was observed for selenium and uranium which preferentially bind to organic matter and to Fe- and Al-oxides. Variation in iron oxide had a strong influence on the K_d of selenium and uranium, but only a moderate influence on the K_d for nickel. The influence on caesium K_d was negligible.

Immobile and dissolved organic matter influenced K_d for nickel and uranium, but did not influence caesium K_d. No model for selenium binding to organic matter is available at present.

The influence of microbial activity on K_d has also been investigated. Organic activity, evaluated as CO_2 pressure, was found to vary with temperature (lower temperatures reduced activity). Uranium was found to have a large dependence on this parameter due to complexation with carbonate ions which keep uranium in solution.

In terms of pH, only caesium K_d was independent of variation since this element is selectively bound and, as such, is not influenced by the presence of hydrogen ions (precipitation reactions were excluded). For U, the results were similar to literature data (Vandenhove et al. 2007[b]).

[b] Vandenhove et al. (2007). Can we predict uranium bioavailability based on soil parameters ? Part 1 : effect on soil solution uranium concentration. Environmental Pollution 145, 587-595.

Overall the most important parameter affecting caesium K_d was clay content although ionic strength (dilution/evaporation) was also important since this affects potassium concentrations in soil solution (potassium being a competitor to caesium for binding sites). In the case of nickel, K_d had a high dependence on pH, ionic strength and the presence of organic matter whereas uranium K_d had a strong dependence on CO_2 pressure and pH. Selenium K_d varied with pH, CO_2 pressure and the presence of iron oxide binding sites. The influence of organic matter on selenium was not evaluated.

In general, a change in one soil parameter can result in a change in K_d of around one order of magnitude (or even more) and changes of this magnitude would occur under agricultural conditions. However, the model demonstrates that these variations can be evaluated such that the influence of environmental conditions on key model parameters such as K_d can be assessed.

Redox zonation has also been evaluated using the model, taking into account the decomposition of organic matter (where it is assumed that decomposition does not cause changes in organic binding sites). It is also assumed that selenium is precipitated as either elemental selenium or FeSe, nickel is precipitated as $Ni(OH)_2$ and uranium as uraninite (UO_2). In K_d calculations the precipitated material is assigned to the solid phase (although it is acknowledged that some may remain present in solution as colloids).

For uranium, a pe range from 4 to 14 under a CO_2 pressure of 3.5 had no influence on K_d whereas below a pe of 4 the K_d dropped due to the decomposition of oxides resulting in the release of ions. The influence of pe on K_d was affected by changes in CO_2 pressure. In the case of caesium however, only a slight decrease in K_d was observed as a result of changing ionic strength with nickel precipitating as $Ni(OH)_2$ at low pe. For selenium, a more complex behaviour is observed. At a pe of 9, selenate in solution is transformed to selenite which is much more tightly bound to Hfo surfaces. The model predicts precipitation of elemental selenium at a pe of 2.5 and precipitation of FeSe at a pe of -0.4 (however no binding of selenium to organic matter was modelled).

From the redox simulations undertaken, it was concluded that redox behaviour is dominated by hydrous oxide dissolution. The k_d for selenium and uranium was greatest under anoxic conditions (under the assumption that precipitates are associated with solid material). Further steps will involve developing the model to allow K_d to be defined for finely dispersed or colloidal material.

4.14 CARBON-14 ASSESSMENT WORK OF SKB

Ulrik Kautsky presented on behalf of Rodolfo Avila (Facilia AB).

Carbon-14 modelling work at SKB was initially focussed on the aquatic environment with uptake to fish in lakes being the principal concern. The approach to the terrestrial system was based on net primary production and isotopic ratios for the uptake of carbon to plants. Mixing with the atmosphere above the plant canopy was represented with a simplified model that was intended to be conservative, providing that sufficiently cautious parameter values were chosen. However, previous work within BIOPROTA indicated a large variability in modelled C-14 concentrations from the different model approaches applied with that of SKB being in the lower end of the range. Recent work at SKB has therefore largely focussed on improving modelling capability for the terrestrial environment.

In the absence of plants, the physics of air movement are relatively easy to incorporate into models; however, plant canopies affect wind dynamics, by causing turbulence that itself affects wind speed, therefore influencing plant uptake through photosynthesis. In order to address plant canopy effects on wind speed and turbulent diffusion, parameters are required in relation to wind speed and eddy

diffusivities at different heights both within and above the plant canopy. A review of data on this issue has been undertaken, which will be published later in the year as SKB report TR-12-05.

On the basis of the review undertaken, a more detailed model has been developed which incorporates additional atmospheric compartments with fluxes between to allow mixing in the atmosphere to be more realistically modelled. The revised model for grasslands and croplands contains three atmospheric compartments (canopy atmosphere and two above-canopy compartments) and one plant compartment. Within the canopy atmosphere, net and gross primary production are distinguished and root uptake has also been incorporated within the model. Plant uptake is still modelled using a specific activity approach and it is assumed that uptake is in the form of carbon dioxide both in terms of foliar and root uptake, although carbonate may also be a source of plant carbon for roots. The C-14 fluxes between compartments are calculated by multiplying the C-14 inventory in the source compartment by a transfer rate coefficient, which is defined as the fraction of inventory that is transferred from the source compartment to the receptor compartment, within a unit of time.

Input parameters to the model include crop height, leaf area index, gross primary production, respiration rate and fraction of assimilated carbon that comes from root uptake. Meteorological data for a reference height of 10 m is used with constants being applied to account for wind change with height. In terms of release, the area over which this occurs is used as an input and the height of the above canopy atmosphere compartments can be defined.

Output from the model includes a profile of wind speed and eddy diffusion coefficients versus height; recycling index (the fraction of C-14 entering the canopy versus that taken up by vegetation); specific activity and C-14 concentration in each atmospheric compartment and the C-14 concentration and specific activity in plants.

It is intended that the model will be validated against literature data.

4.15 SE-79 AND U-238 SERIES SOIL TO PLANT MODELLING

Danyl Perez-Sanchez presented.

A paper has recently been published [Perez-Sanchez et al, 2012[c]] detailing a review of selenium behaviour in soils (including in relation to changing redox conditions and interactions with organic matter), uptake into plants and related parameters such as K_d and CR. The development of a model is also reported.

The basis of the model (which is 1-dimensional and implemented in AMBER) is to reproduce the soil hydrological mass balance as a surrogate for redox (which is strongly driven by soil saturation conditions). Multiple soil layers are incorporated and both drainage and upwelling are considered with water fluxes between soil layers being calculated. The water fluxes between soil layers are used to drive the movement of radionuclides.

Redox conditions are assumed to affect selenium sorption (i.e. K_d) and volatilisation potential. The approach requires minimum and maximum K_d values to be defined to represent oxic and anoxic conditions. The K_d is vertically averaged over each soil layer. Volatilisation is represented by

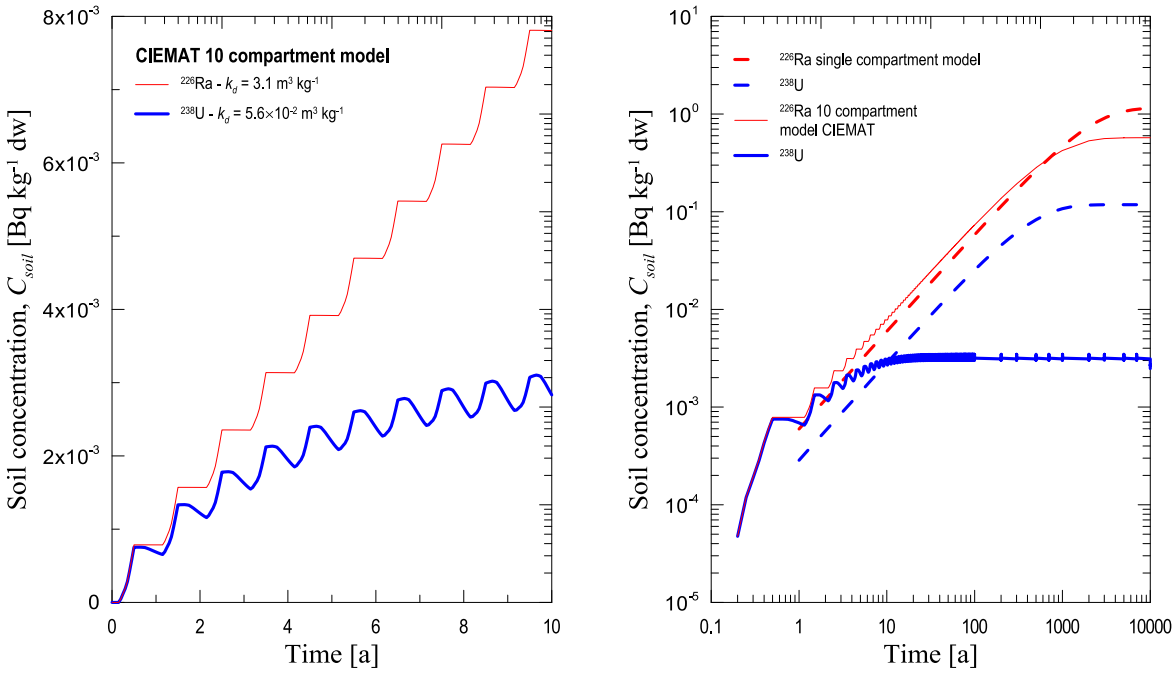
[c] A mathematical model for the behaviour of Se-79 in soils and plants that takes account of seasonal variations in soil hydrology, J. Radiol. Prot. 32: 11–37.

assuming that methylation occurs under anoxic conditions, but that in soil saturation conditions, volatile forms will be dissolved into soil solution. As such, loss of selenium through volatilisation is restricted to the capillary fringe. Plant uptake is a function of root density in each soil layer and the water content of each layer (i.e. K_d). Two broad plant types are considered – perennial plants such as grass that are harvested throughout the year and agricultural crops that are subject to a single cropping per year. The return of organic matter to soil surface is represented.

The reason for developing a hydrological-based soil to plant model was that hydrological conditions in Spain are unique – rainfall events are irregular both in frequency and intensity. The model allows such variations to be evaluated in terms of impact upon plant uptake. Sensitivity analyses have been performed and the results indicate that the model performs as expected.

The model is being modified to allow consideration of the Uranium-238 decay series. Radon is represented by allowing diffusive losses from the system. Overall the revised model structure is similar to that for selenium, but the key difference is the ability to consider multiple radionuclides at one time. For those elements that are not sensitive to changing redox conditions, a single K_d value is applied to all soil layers. Foliar interception or irrigation water is not considered. The model allows radionuclide concentrations over time and with soil depth to be evaluated. However, simplifications have been required – soil characteristics which vary with depth have not all be incorporated to date.

The model has been applied within the EMRAS II WASTE DISPOSAL working group for intercomparison exercise and the intention is to compare the model with another's model approach taking into account different climate conditions within the same scenario, as can be seen in the following figure.



(a) Interannual variation in the concentration of the top 0.1 m of soil as a results of fluctuating water table for the first ten years after the start of irrigation

(b) Long term accumulation in the upper soil over a period of 10 ka

Comparison of the results from the CIEMAT model with variable water table height and those for a single compartment model.

4.16 ASSESSMENT DATA SELECTION

Ari Ikonen presented.

There are a number of drivers that must be taken into account when selecting assessment data, not least of which are the national regulatory requirements. In Finland, the regulator requires that environmental change in terms of land uplift is considered, but no variation in climate type or in terms of human habits should be incorporated within the assessment. There is a clear requirement for data to be derived on the basis of laboratory experiments, site investigations and/or use of natural analogues in preference to generic published data and that the assessment should be conservative (but not overly so). Throughout the assessment timeframe (10,000 years), the development of the site must therefore be considered and the influence of landscape development on the transport and migration of radionuclides evaluated.

In order to evaluate how the land may evolve in the future, the past evolution has been studied and this will be projected to the future. A reference area has been established, however the island of Olkiluoto does not contain lakes and mires which are anticipated to develop as new land areas are formed and, as such, reference lakes and mires have been selected outside the Olkiluoto reference area.

Within the reference area, biotopes have been identified and researched: as known by ecologists at least a century, it is the fertility of the substrate that drives the biological community. In the case of reference lakes and the coastal area, biotopes are delineated according to photic conditions and whether the substrate is hard or soft. Each biotope is described qualitatively in the first instance and then quantitatively as data become available from the site and reference area characterisation programme. Photographic descriptions are also maintained that document seasonal differences in biotopes and support the visualisation of the information and data presented.

The geosphere-biosphere interface zone will develop over time as land uplift processes occur. The key changes will relate to the position of the groundwater table which will lower with time such that access directly to groundwater in the longer term will be restricted to deep-rooting trees. The change in the groundwater table also results in soil formation (podzolisation), i.e. geochemical development, which is also significant in terms of changes in sorption processes.

In order to meet requirements relating to the level of conservatism, the objective is to select data that are ‘moderately’ conservative and to present a range of data around this. This in itself introduces difficulties since the quantity of site data that can be derived is limited both in terms of financial commitment and timescales, which necessitates the use of published data in deriving ranges. Site data can nonetheless be used as the nominal value for input to the assessment. However, even with the use of published data (for which review is required to establish relevance to the site), some data gaps will remain and expert judgement may be required in some instances. The application of available data is being prioritised such that site and reference area data are preferred. In their absence, data from the rest of Finland or Sweden are selected due to the approximate similarity of conditions. Where data gaps remain, literature data is applied or compendium data if necessary. The use of surrogate data is used as a last resort (i.e. application of data from one species to another or from one element to another).

The assessment output, as defined by Finnish regulatory requirements, includes dose to the most exposed group, dose to other people (i.e. a more dispersed release may also be a penalising assessment case) plus dose to plants and animals. Due to the number of different endpoints

considered, it is not possible to be cautious with regard to the selection of assessment data with a single consideration of the data: what would be conservative to one endpoint may not be conservative for another. In particular, differences would be expected between dose assessments for people and less similar other biota. A scenario approach is therefore taken as a means of constraining the data issue.

In order to evaluate the reliability of the dataset, a knowledge quality assessment approach is being applied. The knowledge quality assessment is used, in combination with sensitivity studies that take account of the range of data and how the use of this range could influence the assessment outcome, to identify the main data and computational uncertainties. A quality index is derived for data against which scoring can be undertaken. The index includes considerations such as the robustness of data against timescale and external considerations. Consideration is also given to the applicability of non-site data to site conditions to account for uncertainties in the application of global data within a site context.

The work is in progress and is due to be published at the end of 2012.

4.17 UPDATE ON REACTIVE CHEMISTRY APPROACH TO DETERMINING KDS FOR BIOSPHERE MEDIA

Àngels Piqué presented.

Previously, a project was undertaken by Amphos 21 on behalf of SKB, to develop a reactive transport model to represent the transfer of radionuclides across the geosphere-biosphere interface zone in order to help quantify the retention capacity of the Forsmark near surface deposits (glacial till and clay). The migration of radionuclides from the geosphere to the biosphere can be affected by a number of factors depending upon the radionuclide, as indicated in the table below.

Retention process	C	I	Cl	Nb	Ni	Mo	Se	Tc	Th	U	Cs	Sr	Ra
Sorption onto organic matter													
Sorption onto Fe-Mn-Al oxyhydroxides													
Sorption onto phyllosilicates													
Precipitation as pure phases													
Association with iron sulphides													
Association with carbonates													
Association with sulphates													

Processes likely to be active.

Processes implemented in the models.

Model simulations indicated that the Forsmark till system constitutes a geochemical reactive barrier to the migration of radionuclides with retention occurring as a result of several different processes. Retention was greatest for caesium, uranium and nickel. Strontium was retained to a lesser degree whereas carbon, selenium and radium retention was minimal. However, these simulations were undertaken without taking into account radioactive decay since the primary focus was on chemical behaviour. This could lead to inaccuracies in the simulation results. In the case of Ra-226 for

example, migration in the near-surface system will be determined not only by retention processes affecting Ra-226, but also by those affecting the parent radionuclide Th-230.

A further project was therefore initiated with the objective of determining the effects of introducing the coupled decay and retention of selected radionuclides of thorium, radium, nickel and caesium within the 2D model of the Forsmark till domain.

The initial steps in the project were to calculate repository derived concentrations of radionuclides in boundary water; develop probabilistic sensitivity analysis of key parameters with Monte-Carlo—PHREEQC; and implement decay chains in PHREEQC.

As noted above, there is a range of processes that affect retention of radionuclides. In addition, competition for sorption sites and pH can be important variables. Since major elements in groundwater are not independent of one another, it can be difficult to determine the dependencies of each radionuclide on groundwater parameters. For the probabilistic sensitivity analysis of key parameters, a stochastic modelling approach for trace elements and solid phases was developed. Probability distribution functions were constructed based on data derived from groundwater sampled from deep boreholes at the Forsmark site.

Simulation results indicate that repository-derived thorium retention is affected by the amount of dissolved trace elements competing for sorption sites and by the total available sorption sites. For nickel, retention is affected by the amount of dissolved trace elements (natural Ni, U) competing for sorption sites and by the amount of sorption sites available (e.g. the presence of ferrihydrite and illite).

It is concluded from the work undertaken to date that caesium, nickel and thorium have a high affinity for the solid phase (i.e. a high K_d), but that competition for sorption sites is an important factor when considering retention. The model approach has therefore demonstrated the usefulness in providing a means of identifying key parameters and interactions. Further work is on-going, including 2-dimensional reactive transport simulations with decay chains, deterministic sensitivity simulations of key parameters in the 2-dimensional model and comparison of the reactive transport models both with and without decay chains.

5. NEWS FROM OTHER PROJECTS AND PROGRAMMES

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

5.1 THE IAEA MODARIA PROGRAMME

Ulrik Kautsky presented on behalf of Tobias Lindborg.

The IAEA is in the process of setting up a new programme, Modelling and Data for Radiological Impact Assessments (MODARIA). One of the proposed MODARIA working groups is intended to update consideration of climate modelling, as relevant to the support of safety cases for radioactive waste repositories. The project is being planned to provide:

- a conceptual model for a global reference future (GRF),
- a report describing the model and methods,

- illustrative examples on how the model can be applied,
- dose assessment exercises using site descriptions derived from the GRF methodology and local data, and
- comparisons with other methodologies.

The first technical meeting is planned to take place in Vienna in the week beginning 19 November 2012.

For further information please contact Tobias Lindborg at SKB.

5.2 OVERVIEW OF THE FIRST VERSION OF THE STAR'S STRATEGIC RESEARCH AGENDA

Laureline Février presented.

STAR is an EC funded project to develop a network of excellence in radioecology where radioecology is taken to encompass the transport and transfer of radioactivity and potential impacts on both people and the environment. Radioecology expertise are important input to assessments that can cover a variety of release and exposure situations including normal and future planned operations and accident and post-accident scenarios. Research is required to reduce uncertainties in such assessments, which in turn improves credibility with stakeholders.

In 2009, a European Radioecology Alliance (ERA) was established between eight organisations with the goal of developing a strategic research agenda (SRA) that would integrate their research programmes. The development of the SRA has been mandated to a European Network of Excellence with funding provided by the EC, giving rise to STAR – Strategy for Allied Radioecology. The objective of the SRA is to provide a suggested prioritisation of research topics in radioecology, which could improve research efficiency and more rapidly advance the science. It was formed by considering recent changes in international policy such as requirements for protection of the environment; scientific advancements (e.g. epigenetics, bystander effects and population effects from multi-generational exposure); improving credibility with stakeholders; the need to address scientific deficiencies and integration issues (such as multi-stressor assessments); potential future risks and early lessons from the Fukushima accident.

Three scientific challenges have been identified in the developing SRA – human and wildlife exposure characterisation; wildlife effects characterisation; and risk characterisation and management.

For human and wildlife exposure characterisation, the objective is to predict exposures to people and biota more robustly by improving understanding of what influences radionuclide transport in the environment and quantifying key processes that influence radionuclide transfers. Four research lines have been identified:

- To identify and then mathematically represent key processes affecting the transfer or radionuclides and resultant exposures to people and biota. This research line would include identifying where uncertainties could feasibly be reduced, justifying required research that would support model development and identifying the level of model complexity required for specific exposure situations. The influence of differences in source term upon exposure is also an important consideration since differences in chemical form is likely to influence environmental behaviour.

- To acquire the data necessary to parameterise the key processes controlling the transfer of radionuclides. This could involve the development of new methods for extrapolation, use of statistical approaches or the development of specific laboratory projects and/or field studies.
- To develop radionuclide transfer and exposure models incorporating physical, chemical and biological interactions that would enable exposure assessments to be made on appropriate spatial and temporal scales. This would require spatial and temporal variability in habitat utilisation to be incorporated into models and the representation of processes at interfaces between ecosystem compartments.
- To represent radionuclide transfer and exposure at the landscape or global environmental level, including consideration of uncertainty. This could involve the use of GIS tools to identify sensitive environmental areas and/or to integrate background levels or changes in exposure relating to the movement of biota.

For wildlife effects characterisation, the vision is to gain, through improved mechanistic understanding of processes inducing radiation effects at different levels of biological organisation, the ability to accurately predict effects under realistic exposure conditions. Much of the data currently available on radiation effects on biota are not relevant to ecological consequences: data are limited with regard to population responses, reproductive effects and chronic exposure conditions. Five research lines have been identified:

- To investigate, at a mechanistic level, how processes link radiation effects in wildlife from molecular to individual levels of biological complexity.
- To improve understanding of what causes intra- and inter-species differences in radiosensitivity. This would consider differences in DNA damage/repair between species and how this links to radiosensitivity, the influence of heterogeneity in body burden to biological responses and whether occupied habitats or differences in behaviour and/or feeding regime contribute to radiosensitivity.
- To understand more fully the interaction between ionising radiation and other stressors.
- To understand the mechanisms underlying multi-generational responses to long-term realistic exposure conditions, including the transmission of genomic damage through generations.
- To investigate how radiation effects combine at higher levels of biological organisation, including trophic interactions and whether radiation exposure affects the integrity of ecosystems in terms of function and community interactions.

For risk characterisation and management, the vision is to develop the scientific foundation for the integration of human and environmental protection and their associated management systems. The objective is to consider all aspects of risk management through a multi-criteria approach that could be integrated within decision support tools. This would provide the basis for setting remediation thresholds, which would vary according to contaminants present and the level of contamination, both in terms of concentration (or activity) and land area affected. Six research lines have been identified:

- To integrate uncertainty and variability arising from modelling radionuclide transfer, exposure and effect into risk characterisation by considering simultaneously the variability in doses and

that associated with the radiosensitivity of species and to integrate temporal variability in transfer, exposure and effects over the period of interest for the risk assessment.

- To integrate human and environmental protection frameworks. This would involve consideration of where harmonisation of approaches is justifiable and beneficial and then to focus on the development of integrated assessment methods for evaluating transfer, exposure and effects/risk.
- To integrate risk assessment frameworks for radionuclides and chemicals to reinforce similarities in frameworks and to develop a risk assessment framework that could be applied to multiple stressors.
- To provide a multi-criteria perspective to support optimised decision making by integrating decisions support tools, such as those relating to economics and sociology, and introducing multi-criteria decision analysis to guide decision making processes.
- To integrate ecosystem services, ecological economics and ecosystem approaches within radioecology in order to integrate the concept of sustainability, environmental indicators and sustainable use of resource into the definition of specific protection goals and the development of new ecological risk assessment methods.
- To integrate decision support systems for people and the environment and to harmonise approaches between planned and emergency situations.

This first version of the SRA due to be open shortly for public consultation at the STAR website (www.star-radioecology.org). Other aspects of the strategic agenda relating to education, recruitment, maintenance of key infrastructures and knowledge management are still to be developed and a roadmap for the SRA will be developed that details more precisely what is required and how components can be achieved.

6. FORWARD BIOPROTA PROGRAMME

Prior to the 2012 workshop, two project proposals were distributed. These relate to a forward programme for reducing C-14 assessment uncertainties and a project to investigate appropriate temporal and spatial scales of assessment for non-human biota as applied to long-term safety assessments. Brief overviews of the presentations made with regard to these proposals are detailed below. In addition, presentations were made in relation to work due to be undertaken by Ontario State University on C-14 and proposals for further work within BIOPROTA on the geosphere-biosphere interface zone and for a specialised workshop on long-term biosphere impact assessments.

6.1 TEMPORAL AND SPATIAL SCALES IN ASSESSMENT OF RADIOLOGICAL ENVIRONMENTAL IMPACT

Mike Wood presented a proposal with the primary objective to ensure that appropriately assessed environmental radionuclide concentrations are used in non-human biota radiation dose assessment, relevant to the populations of species which are the focus of environmental protection objectives applied to the post-closure radiological assessment of radioactive waste repositories.

Secondary objectives include:

- Identification of need to clarify protection objectives in terms of relevant endpoints (e.g. doses to relevant populations over relevant temporal and spatial scales);
- Identification of site characterisation needs which are relevant to making the necessary temporal and spatial scale assessments; and,
- Identification of relevant research necessary to meet these needs.

Output would include:

- A documented rationale for addressing spatial and temporal scales within NHB dose assessments;
- Identification of relevant scales for representative reference organism populations;
- Evaluation of commensurability with human scales;
- Identification of modelling requirements to address scale issues in NHB dose assessments;
- Demonstration of application to a specific case study, and
- Presentation and dissemination in a format that meets the interests of BIOPROTA organisations, and contributes to wider international thinking in this area.

A second version of the proposal is due to be produced in the light of discussion at the workshop.

6.2 MODELLING APPROACHES TO C-14 IN SOIL-PLANT SYSTEMS AND IN FRESHWATER ENVIRONMENTS

Karen Smith presented.

A phase II BIOPROTA C-14 project completed in 2011. The project involved undertaking a FEP analysis and development of an interaction matrix, focussed on soil to plant transfer, plus a model intercomparison exercise. However, variability in model output was observed which primarily related to assumptions around the behaviour of C-14 in the plant canopy atmosphere. A further work programme was therefore proposed, in part to address these remaining uncertainties, but also to extend C-14 considerations into the freshwater environment, particularly in relation to uptake of C-14 by fish. A proposed work programme was circulated prior to the workshop and feedback had been received by a number of sponsoring organisations. Some revisions were proposed and these were therefore presented for discussion.

The initial proposal contained five tasks:

- Task 1: Attendance of 21st International Radiocarbon Conference (July 2012). Work completed to date on C-14 and the planned forward programme would be presented and a publication prepared for a peer-reviewed journal (Radiocarbon Journal). Initial feedback on this task has all be very positive.
- Task 2: Review of plant canopy models and their parameterisation. The suggestion had been to review parametric assumptions for key processes associated with the plant canopy and to consider how different conceptual models are differently relevant. However, SKB have indicated that some of this review work has been undertaken by themselves with a publication

due at the end of 2012. The revised approach is therefore to organise review of the work undertaken by SKB, and that of other organisations such as LLWR. Reviewers would include those experts involved in the previous and on-going assessment work, but also the intention is to introduce wider expertise, such as may be identified at the Radiocarbon Conference and elsewhere.

- Task 3: C-14 uptake into freshwater fish. A review of data on the incorporation of C-14 into fish was proposed, taking into account field work, for example, as carried out in Canada. The task would also include consideration of the conceptual basis of available models, both dynamic and equilibrium and review the parametric assumptions for key processes. A model intercomparison exercise would then be used as the basis for developing recommendations on how to use the alternative modelling concepts as a complimentary set.

- Task 4: Workshop. The workshop would provide the opportunity to present and discuss the output from tasks 2 and 3 and would include invited experts to enhance knowledge sharing.

Following feedback from sponsoring committee organisations, it is proposed that tasks 3 and 4 are combined such that a specialised workshop be organised to which C-14 experts are invited. The workshop would provide an opportunity to discuss the issues associated with long-term C-14 modelling in freshwater environments and to prioritise these in terms of requirements for improving long-term assessment models (both in terms of process understanding and parameterisation). The prioritised research issues could then be used by sponsoring organisations as the basis for arranging a co-ordinated research programme to which a radiocarbon expert (or experts) would be directly contracted to take forward the agreed work programme. In order to facilitate this, relevant experts will be identified where possible during the Radiocarbon conference. However, sponsoring organisations would also be responsible for identifying relevant experts that they would wish to attend the workshop.

SKB have kindly offered to host the workshop in Stockholm either in late autumn 2012 or early spring 2013.

The proposed revisions were positively received and a revised proposal will therefore be developed and circulated to potential sponsoring organisations.

6.3 OSU, CHALK RIVER LABORATORIES & C-14 (AND A LITTLE BIT ABOUT CHERNOBYL)

David Bytwerk presented.

The chalk river site is located on the eastern border of Ontario, Canada. There has been a lot of research conducted at the site over the years and this has led to contaminant build up. The site is well characterised and has a high water table (within 2 metres of the surface) and sandy soils, which allows for the rapid migration of contaminants from waste storage areas.

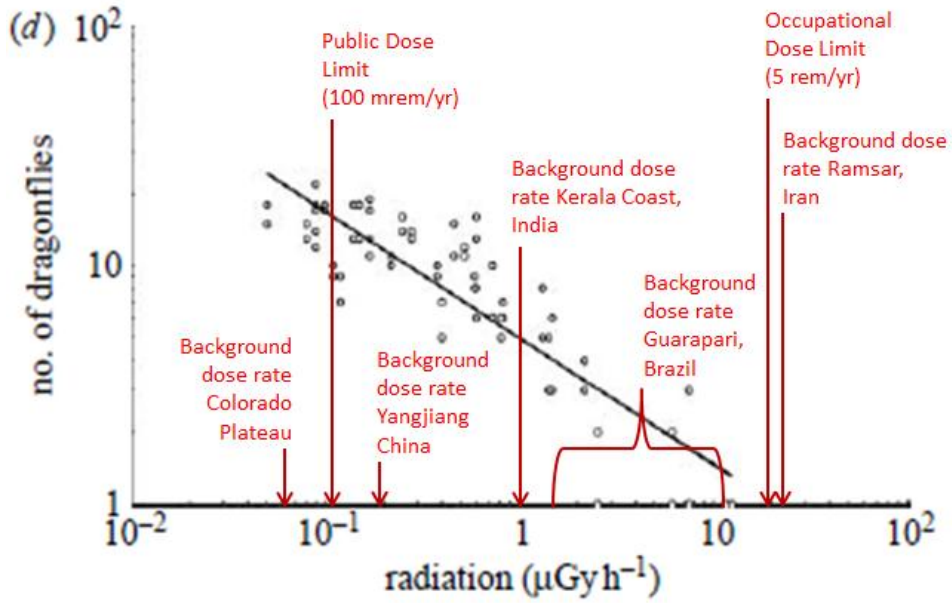
The Duke Swamp area of the site, which will be the focus of field work by OSU in summer 2012, has significant C-14 contamination – the annual input is some tens of GBq in the form of carbon dioxide. Tritium is also an issue in groundwater. The source term is poorly characterised.

The site is situated in a depression such that there is minimal air mixing except during storm events. The dominant tree species are spruce, cedar and maple.

The primary aim of the field work is to evaluate biota dose effects across a dose gradient at the site; however there is also the opportunity to undertake a sampling programme relating to C-14 that could

provide a data set for model validation. Feedback is therefore requested on what measurements would be interesting in this regard. [NWMO expressed particular interest in the field work outlined and a proposal is requested].

In terms of Chernobyl, a number of papers have been published recently in peer-reviewed journals on adverse radiation effects on the ecology of the area. These papers have been published by Anders Pape Møller and Timothy A. Mousseau on the basis of two field trips to the region, the results of which are somewhat unexpected and contradict the general view that removing people from the region has improved the ecology. For example, published results indicate that the abundance of insects and spiders are very much reduced (although the means of presenting data on a log-log scale has served to emphasise the relationship). The data presented have been compared against known background dose rates which indicates that effects are being observed at dose rates much lower than those allowable for people (as indicated in the figure below). If the data in these articles are correct, it would imply that the existing literature on the biological effects of radiation is fundamentally flawed and that the science supporting radiation protection needs fundamental reworking.



Results are not limited to insects, but include a range of species (including raptors) and are triggering news coverage. Letters are therefore being prepared to journal editors to challenge the conclusions and funding is being sought to enable follow-up research to be undertaken. The authors have been contacted by a number of researchers to allow for independent scrutiny, but to date, the data have not been shared. The level of exposure being gained by the authors means that the issue must be addressed and BIOPROTA is invited to provide input. Some of the papers published include:

- Møller, A.P., and T.A. Mousseau. 2009. Reduced abundance of insects and spiders linked to radiation at Chernobyl 20 years after the accident. Biology Letters of the Royal Society 5(3): 356-359.
- Møller, A. P., A. Bonisoli-Alquati, G. Rudolfsen, and T.A. Mousseau. 2011. Chernobyl birds have smaller brains. PLoS One 6(2): e16862.

- Møller, A. P., T.A Mousseau. 2008. Reduced abundance of raptors in radioactively contaminated areas near Chernobyl. Journal of Ornithology, 150(1):239-246.
- Møller, A.P., and T.A Mousseau. 2007. Determinants of interspecific variation in population declines of birds after exposure to radiation at Chernobyl. Journal of Applied Ecology, 44: 909-919.

Information detailing the type of coverage that the publications are triggering is provided by the following links:

- Scientific meltdown at Chernobyl? http://www.scientificamerican.com/blog/post.cfm?id=scientific-meltdown-at-chernobyl-2009-03-24
- Is Chernobyl a Wild Kingdom or a Radioactive Den of Decay? http://www.wired.com/magazine/2011/04/ff_chernobyl/5/
- Chernobyl zone shows decline in biodiversity http://www.bbc.co.uk/news/science-environment-10819027
- Chernobyl 'shows insect decline' http://news.bbc.co.uk/2/hi/science/nature/7949314.stm

6.4 INTERNATIONAL WORKSHOP ON ASSESSING LONG-TERM ENVIRONMENTAL IMPACTS

Graham Smith presented.

Environmental impact and human health assessments ("EIAs") are used to support decisions on the management and disposal of radioactive and hazardous waste. These EIAs have to address a wide range of protection objectives, ecosystems and timeframes. This creates significant challenges to the design of the EIAs and in the development of corresponding relevant scientific support. It is therefore proposed to hold a workshop with the following objectives:

- Assessment endpoints (What is calculated as a measure of environmental and or human health impact?)
- Assessment methodologies for disposal radioactive and hazardous waste,
- Key processes which affect the release and disposition of radionuclides and other pernicious pollutants within the environment,
- 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 they affect 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 sharing experience on the above topics, it is hoped to develop ideas for complementary, consistent and appropriate scientific support in different assessment contexts.

Several organisations have already expressed support for the idea and interest in participation. A full proposal is therefore to be prepared and distributed for consideration.

6.5 MODELLING RADIONUCLIDE BEHAVIOUR AT THE GBIZ, ACCOUNTING FOR ENVIRONMENTAL CHANGE AND REDOX SENSITIVITIES

Graham Smith presented on behalf of Mike Thorne.

Bearing in mind previous collaborative work within BIOPROTA related to redox sensitive radionuclides and processes in Geosphere-Biosphere Interface Zone (GBIZ), see Appendix A, this proposal was made to develop a scenario-based approach to identifying and investigating processes of common interest. Features of the GBIZ include, among other things:

- Surface and sub-surface hydrogeology,
- Surface and subsurface hydrogeochemistry,
- Spatial and temporal variations in pH and redox conditions,
- The development and activity of microbial communities,
- Overall biogeochemical cycling of trace and major elements and contaminants, including relationships between contaminants and specific trace or major elements, and
- Contaminant transport in 1-, 2- and 3-dimensions, as influenced by hydrogeology, hydrogeochemistry and biogeochemical cycling

All of the above are closely interrelated and but is just one way of partitioning a strongly coupled system. Alternative approaches to partitioning the issues would be considered as part of the project. Mike suggested the following possible characteristics of a useful scenario, which would drive the examination of alternative approaches:

- Multiply layered sedimentary system, but with individual layers that are discontinuous or of limited lateral extent
- Strong hydrogeological contrasts between layers giving the potential for perched water
- Localised deposits of different textures and/or organic matter content

In discussion, it was noted that the proposal is a natural progression of work competed on the U-238 decay chain, and it could include extension of that work to the shorter-lived progeny beyond Ra-226, including radon emanation and dose assessment. The type of study also reflects the modelling work presented by Danyl Perez-Sanchez and Jordi Vives. Interest was expressed in further consideration of Tc-99. Accordingly, a full proposal is due to be prepared and distributed to potential sponsors.

6.6 2013 FORUM MEETING

The 2013 BIOPROTA workshop will be hosted by ARAO in Slovenia. The date of the workshop is to be confirmed, but is likely to take place in May.

Following recommendations arising from the Sponsoring Committee meeting, it is intended that the workshop will be organised back-to-back with a specialised workshop.

6.7 BIOPROTA CHAIR FOR 2012/13

Simon Norris (NDA RWMD) has volunteered, with Ray Kowe (also NDA RWMD) to continue to chair the forum for the coming year.

The work of Simon in chairing the forum in 2011/12 is gratefully acknowledged.

APPENDIX A: BIOPROTA PUBLICATIONS AS AT MAY 2012

Topical Workshop Reports

1. BIOPROTA. Report of a Workshop to Evaluate Primary Features, Events and Processes Occurring in the Geosphere-Biosphere Interface Zone, and to Identify Methods for their Resolution, 12-14 September 2005, Sant Cugat, Spain.
2. BIOPROTA. Report of an International Forum on Cl-36 in the Biosphere, 27-28 September 2006, Châtenay-Malabry, France.
3. BIOPROTA. Report of the ProBiota International Forum on the Application of Guidance and Methodologies for Assessing Radiation Impacts on Non-Human Biota from Radioactive Waste Disposal Facilities. 31 January-1 February 2007, Lappeenranta, Finland.
4. BIOPROTA. Report of an International Forum on Se-79 in the Biosphere, 5-6 May 2008, Wettingen, Switzerland.
5. BIOPROTA. International workshop on the environmental behaviour of Radium, 24 June 2010, Châtenay-Malabry, France.
6. BIOPROTA. International workshop on the Functioning of the Geosphere-Biosphere Interface Zone, 6 - 8 September 2011, Louvain la Neuve, France.

Technical Reports

1. BIOPROTA (2004). Theme 1: Specialised Database, version 1.1. A database prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. September 2004.
2. BIOPROTA (2005a): Model Review and Comparison for Spray Irrigation Pathway. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: U Bergström (Task Leader), A Albrecht, B Kaynar, G Smith, M C Thorne, H Yoshida and M Wasiolek. Published on behalf of the BIOPROTA Steering Committee by SKB, Sweden.
3. BIOPROTA (2005b): Modelling the Inhalation Exposure Pathway. A report prepared within the international collaborative project BIOPROTA. Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: M Wasiolek (Task Leader), A Agüero, A Albrecht, U Bergström, H Grogan, G M Smith, M C Thorne, M Willans and H Yoshida. Published on behalf of the BIOPROTA Steering Committee by BNFL (Nexia Solutions Ltd.), UK.
4. BIOPROTA (2005c): Model review and comparison for C-14. A report prepared within the international collaborative project BIOPROTA. Key Issues in Biosphere Aspects pf Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: S Shepard (Task Leader) and M C Thorne. Published on behalf of the BIOPROTA Steering Comittee by UK Nirex Ltd., UK.
5. BIOPROTA (2005d): Model Intercomparison with focus on accumulation in soil. A report prepared within the international collaborative project BIOPROTA. Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: A Albrecht, C Damois, E Kerrrigan, R

Klos, G M Smith, M Thorne, M Willans and H Yoshida. Published on behalf of the BIOPROTA Steering Committee by ANDRA, France.

6. BIOPROTA (2005e): Application of Biotic Analogue Data. A report prepared within the international collaborative project BIOPROTA. Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: E Kerrigan (Task Leader), G M Smith and M C Thorne. Published on behalf of the BIOPROTA Steering Comittee by UK Nirex Ltd., UK.
7. BIOPROTA (2005f): Modelling Processes in the Geosphere Biosphere Interface Zone. A report prepared within the international collaborative project BIOPROTA. Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: P Pinedo and G M Smith (Task Leaders), A Agüero, A Albrecht, A Bath H Benhaderrahmane, F van Dorp, U Kautsky, R Kos, A Laciok, T Milodowski, J-O Selroos, I Simón, D Texier, M C Thorne and M Willans. Published on behalf of the BIOPROTA Steering Comittee by CIEMAT, Spain.
8. BIOPROTA (2006a): Theme 1: Specialised Database, version 2.0. A database prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. September 2006.
9. BIOPROTA (2006b): Guidance on Site-Specific Biosphere Characterisation and Experimental Research and Field Research Protocols. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-Term Impact of Contaminated Releases Associated with Radioactive Waste Management. Main Contributors: E Leclerc-Cessac, M C Thorne and G Thomson. Published on behalf of the BIOPROTA Steering Comittee by ANDRA, France.
10. Limer L, Albrecht A, Bytwerk D, Marang L, Smith G and Thorne M (2009). Cl-36 Phase 2: Dose Assessment Uncertainties and Variability. Final report for the BIOPROTA programme. Published as external report by ANDRA, ANDRA DRP.CSTR. 09.0026, Châtenay-Malabry, France.
11. Limer L, Albrecht A, Marang L, Smith K, Thorne M C, Wiebert A, Xu S and Smith G (2009). C-14 Long-Term Dose Assessment: Quantitative Model Comparison and Development, Part I. Report prepared under the BIOPROTA international programme.
12. Limer L, Albrecht A, Marang L, Miquel S, Tamponnet C, Nakai K, Gierzewski P, Thorne M and Smith G (2008). Investigation of Cl-36 Behaviour in Soils and Uptake into Crops. Report prepared under the international BIOPROTA programme. Published as external report by ANDRA, ANDRA C.RP.ASTR.08.0048, Châtenay-Malabry, France.
13. Smith K, Sheppard S, Albrecht A, Coppin F, Fevrier L, Lahdenpera A-M, Keskinen R, Marang L, Perez D, Smith G, Thiry Y, Thorne M and Jackson D (2009). Modelling the Abundance of Se-79 in Soils and Plants for Safety Assessments of the Underground Disposal of Radioactive Waste. Report prepared under the BIOPROTA international programme.
14. Smith K, Robinson C, Jackson D, De Laz Cruz I, Zinger I and Avila R (2010). Non-human Biota Dose Assessment: Sensitivity Analysis and Knowledge Quality Assessment (September 2010). Report prepared under the BIOPROTA international programme. Published as Posiva Working Report 2010-69 by Posiva, Olkiluoto, Finland.
15. Limer L M C, Smith K, Albrecht A, Marang L, Norris S, Smith G M, Thorne M C and Xu S (2011). C-14 Long-Term Dose Assessment in a Terrestrial Agricultural Ecosystem: FEP Analysis, Scenario Development, and Model Comparison. Report prepared under the BIOPROTA international programme. To be published as SSM technical report.
16. Smith K, Jackson D and Wood M D (2012). Demonstrating Compliance with Protection

Objectives for Non-Human Biota within Post-closure Safety Cases for Radioactive Waste Repositories. Report prepared under the BIOPROTA international programme.
17. Smith K, Albrecht A, Thorne M, Coppin F, Ikonen A, Perez-Sanchez D, Smith G and Limer L (Final Draft with sponsors for comment). Se-79 in the Soil-Plant System. Phase 2: Approaches to Modelling. Report prepared under the BIOPROTA international programme.
18. Limer L M C, Albrecht A, Hormann V, Gallerand M-O, Medri C, Perez-Sanchez D, Smith K, Smith G and Thorne M (Final Draft with sponsors for comment). Improving Confidence in Long-term Dose Assessments for U-238 Series Radionuclides. Report prepared under the BIOPROTA international programme.
19. Smith G M, Molinero J, Delos A, Valls A, Smith K, Conesa A, Xu S, Hjerpe T and Medri C (Draft with sponsors for comment). Reference Approach for Human Intruder Dose Assessment for Deep Geological Disposal. Report prepared under the BIOPROTA international programme.

Main and Annual Workshop Reports

1. BIOPROTA (2002). Constitutive BIOPROTA workshop, Châtenay-Malabry, France, 12-14 June. Hosted by ANDRA.
2. BIOPROTA (2002). I BIOPROTA workshop, Oslo, 29-31 October. Hosted by NRPA.
3. BIOPROTA (2003). II BIOPROTA workshop, Nagra, Wettingen, Switzerland, 6-7 May. Hosted by Nagra.
4. BIOPROTA (2003). III BIOPROTA workshop, Paris, 22-24 September 2003. Hosted by ANDRA.
5. BIOPROTA (2004). V BIOPROTA workshop, Stockholm, Sweden, 3-4 May, 2004. Hosted by SKB.
6. BIOPROTA (2004). VI BIOPROTA workshop, Pori, Finland, 22-24 September, 2004. Hosted by Posiva.
7. BIOPROTA (2005). VII BIOPROTA workshop, Ottawa, Canada, 11-12 May 2005. Hosted by NWMO.
8. BIOPROTA (2006). VIII BIOPROTA workshop, Oxford, United Kingdom, 16-18 May 2006. Hosted by UK Nirex Ltd.
9. BIOPROTA (2007). IX BIOPROTA workshop, Rez, Czech Republic, 23-25 May 2007. Hosted by NRI.
10. BIOPROTA (2008). X BIOPROTA workshop, Wettingen, Switzerland, 7-9 May, 2008. Hosted by Nagra.
11. BIOPROTA (2009). XI BIOPROTA workshop, Madrid, Spain, 6-8 May 2009. Hosted by CIEMAT.
12. BIOPROTA (2010). XII BIOPROTA workshop, Stockholm, Sweden, 24-27 May 2010. Hosted by SKB.
13. BIOPROTA (2011). XIII BIOPROTA workshop, Hamilton, Canada, 18-19 June 2010. Hosted by NWMO.

A variety of papers and presentations has also been made at scientific conferences and in peer reviewed journals.

7.

APPENDIX B. LIST OF PARTICIPANTS

Participant	Affiliation
Ali Hosseini	NRPA, Norway
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Participant	Affiliation
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