

BIOPROTA

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

Report of the Ninth Workshop

**Rez, Czech Republic
23-25 May 2007**

Hosted by Nuclear Research Institute

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Preface

The report is presented as working material for information. The content may not be taken to represent the official position of the organisations involved.

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1. INTRODUCTION

1.1 Objectives of the Ninth BIOPROTA Workshop

The objective of the workshop was to update interested parties on the progress since the last meeting in May 2006 on the various tasks supported through BIOPROTA and to provide a Forum for continuing exchange of information and discussion about additional topics of interest. It was intended that discussions would highlight continuing areas of common interest upon which future BIOPROTA tasks could be built. The meeting therefore focused on progress to date and implementation of a future work plan.

The workshop opened with an introduction by Antonín Vokál, chief of the Waste Disposal Department at the Nuclear Research Institute (NRI), Czech Republic. This was followed by agreement of the draft agenda for the workshop and introductions by participants with a particular focus on their areas of interest in relation to the Forum.

1.2 Report structure

The remainder of this report provides:

- ◆ An overview of the progress made in 2006/07;
- ◆ A summary of presentations made by participants on their biosphere programmes and any challenges faced;
- ◆ An introduction to potential new tasks that were discussed and an overview of proposals circulated in 2006 for consideration by the Forum; and,
- ◆ An overview of discussions of new tasks and proposals for the way forward in 2007/08.

1.3 Participation

There were 24 participants from 10 countries, representing a range of operators, regulatory bodies, and technical support organisations. Participants are listed in Appendix A.

2. PROGRESS TO DATE

2.1 The BIOPROTA Database

In 2005/06 a task was undertaken to collate available data relevant to the key radionuclides and biosphere processes relevant to performance assessments for radioactive waste management facilities for entry into a standalone databook tool. However, due to software issues, entry of collated data into the databook had not been possible. In 2006/07, software issues were addressed and collated data were entered into the databook by Mike Thorne. In entering data, the functionality of the databook tool has been demonstrated through the use of multiple axes for data entry or addition of tables for complex data. Version 2.1 of the databook was distributed, along with an accompanying user guide, to sponsoring organisations in November 2006.

Thoughts on the usability of the databook and ideas for further progressing the databook are invited from participants.

2.2 Theme 3: Site Characterisation, Experiments and Monitoring

The Theme 3 report 'Guidance on Site-specific Biosphere Characterisation and Experimental Research and Field Research Protocols' was published in autumn 2006. The emphasis of the report is on providing guidance on the design of site-specific biosphere characterisation programmes for repository sites. However, it was noted that the questions arising in relation to site characterisation programmes for radioactive waste repositories are also relevant to the long-term management of contaminated land.

The Theme 3 report is intended to provide an overview of the issues associated with site characterisation. It is intended that further work will progress in this area to provide further guidance on site-specific considerations in relation to site characterisation.

2.3 Iodine in Peat Bogs

Results from an 18-month study into the behaviour of iodine in a peat bog were presented by post-doctoral research worker Sophie Maillant. Peat bogs can act as potential sinks for iodine due to their low-lying position combined with organic rich composition. The study is co-ordinated by Elisabeth Leclerc and has received funding from ANDRA, Posiva, SKB and Nirex (now the NDA (RWMD))¹.

The focus of the study is on *in situ* field behaviour of iodine in a low-lying, organic rich peat bog, located on the Canadian Shield that received a point-source input of stable iodine in 1987. The intention of the study was to increase understanding of the behaviour of iodine in relation to organic matter through the study of:

- ◆ The fate and speciation of iodine along the carbon cycle within the peat bog;

¹ On 2nd April 2007, the majority of Nirex staff were transferred to the NDA. The NDA will now perform the functions previously undertaken by Nirex and this is being implemented through a new directorate that has been established, the Radioactive Waste Management Directorate (RWMD).

- ◆ The influence of redox potential on iodine sorption; and,
- ◆ The sorption of iodine onto different organic materials.

Fate and speciation along the carbon cycle

Only small quantities of iodine were associated with the plant cycle of the peat bog; the majority was associated with the organic matter within the peat. Studies on cyperaceae (sedges) and poaceae (grasses) indicated that leaves could accumulate concentrations of up to 400 ppm. The greatest quantities of iodine were associated with older senescent leaves. From the study, it was apparent that iodine becomes fixed to organic matter during biodegradation and was largely associated with polyphenolic substances.

Influence of redox potential

Iodine tended to be located toward the surface of the peat bog, associated with polyphenolic substances, rather than at depth. Therefore, seasonal variation in redox potential (Eh) and iodine sorption (Kd) were simultaneously measured to determine if any link was evident.

Eh was found to decrease from the surface to a depth of 30-40 cm, but increased at 50 cm depth. A large drop in Eh was recorded in relation to rainfall events. Kd was slightly higher at the surface of the bog to a depth of 25 cm after which point an abrupt decrease was recorded. Rainfall events resulted in decrease in Kd, which was most evident at the surface of the bog. Analysis of these results is ongoing.

Sorption on organic materials

In order to obtain chemically different organic materials, peat was thermally matured by heating under pressure, which resulted in the break down of large molecules. The subsequent chemical structure of the peat and iodine sorption coefficients were measured. Physical parameters such as particle surface area were found to have a large influence on iodine sorption. However, no obvious relationship was found between organic matter chemistry and iodine sorption.

The final report from the research study is currently under preparation and will be made available shortly. Scientific papers are also being prepared and will be submitted for peer review and publication in relevant journals.

2.4 Behaviour of Chlorine-36 in the Biosphere

An international forum was held in Chatenay-Malabry near Paris in September 2006, hosted by ANDRA, on the behaviour of Cl-36 in the biosphere that was attended not only by BIOPROTA participants, but also by a number of chlorine specialists. Discussions during the forum identified a number of uncertainties associated with Cl-36 behaviour, particularly with its accumulation in soil and uptake into crops. The published report of the Cl-36 forum was distributed to participants and has been made available on the BIOPROTA webpage (www.bioprota.com).

A new exercise arose as a result of the forum to compare various modelling approaches, including traditional methods involving equilibrium sorption in soil and concentration ratios for root uptake (e.g. the model used in the IAEA BIOMASS reference biospheres examples), specific activity models, and more detailed process oriented models that take account of the interaction between hydrology and crop dynamics). Further information on this task is presented in Section 4 of this report.

2.5 Protection of the Environment from Long-Term Releases of Long-Lived Radionuclides

In January/February 2007 an international forum entitled 'Application of the latest guidance on protection of the environment from radiation and impacts on non-human biota from long-term releases of long-lived radionuclides (proBiota)' was held at Lappeenranta, Finland, hosted by Posiva. The forum provided the opportunity to discuss issues associated with the assessment of impacts on non-human biota (NHB) resulting from releases of radionuclides from waste repositories. The meeting was attended by BIOPROTA participants and NHB assessment experts from the EC ERICA and ICRP Committee 5 work programmes.

A number of issues were highlighted during discussions, primarily in relation to data gaps and uncertainties associated with available assessment methodologies. As such, it was recommended that consideration be given to a task within BIOPROTA to conduct a sensitivity analysis to identify the key uncertainties/data gaps to enable future work to focus on those areas of uncertainty of greatest importance to NHB dose assessments. A proposal for such a study was therefore developed by Ari Ikonen for consideration in the 2007/08 work programme and is summarised in Section 5.

3. CONTINUING CHALLENGES

In Session 2 of the workshop, participants were invited to provide an overview of their biosphere programmes and to identify any issues arising within these programmes. An overview of the presentations and discussions is provided below.

3.1 Biosphere Models of Czech Specific Sites

Jiří Landa presented results from an assessment of dose resulting from soil contamination from a well as defined under BIOPROTA Theme 2, Task 4. The assessment was conducted using three models constructed within the Amber modelling tool. These comprised:

- ◆ a Farmstead model that considered water ingestion, soil inhalation and consumption of food produce (vegetables and cow products);
- ◆ a Highland model that is comprised of two parts. The first part was similar to the Farmstead model, but considered pigs instead of cows and potatoes and vegetables were the non-animal produce consumed. The second part simulated staying in a wood and included mushroom ingestion.
- ◆ a Fishpond area model where contamination from soil and pond water are considered and fish, poultry and potatoes are the primary ingestion routes.

Loss of radionuclides from soil was investigated through consideration of decay, percolation loss and loss by cropping processes (in second calculation). The inclusion of cropping processes resulted in a significant reduction of mainly ¹³⁷Cs soil concentrations in the Farmstead model.

In discussions it was noted that cropping is also an important factor for ¹³⁷Cs since much of what is cropped from a field is returned under variable timescales to ensure soils remain useable for future crops. It was therefore suggested that this process should be further considered in relation to future ¹³⁷Cs tasks and discussions.

Mike Thorne also highlighted the need to consider not only milk and meat in relation to the uptake and distribution of radionuclides in animals, but also offal to ensure accurate modelling of radionuclide behaviour and subsequent dose through consumption.

Questions were also raised as to the suitability of concentration factors (CF) for ¹⁴C from water to fish in the Fishpond model, which were derived from IAEA document TRS-364. This document is currently being updated as part of the current IAEA EMRAS programme and there has been considerable discussion as to whether fish uptake of ¹⁴C should be related to organic carbon or dissolved inorganic carbon. Consideration should therefore be given in modelling studies as to the applicability of currently recommended CF values.

3.2 Posiva Current Situation

Ari Ikonen introduced the Assessment Portfolio approach that is being used for the Safety Case Assessment (SCA) at Posiva for the Olkiluoto waste repository. A site description report has been completed that will soon be available on the Posiva

website (www.posiva.fi) and ecosystem forecasts have been undertaken to predict future landscape on the basis of sediment typology and seabed topography.

The SCA considers a number of main cases where doses from the use of the landscape are calculated, but also considers complementary cases. These include:

- ◆ Use of the landscape dose factor approach, as well as dose indicators for a drinking water well and a agricultural well;
- ◆ Conversion of forests to agricultural areas;
- ◆ Contamination of seabed and subsequent evolution to terrestrial land;
- ◆ Warmer climate scenarios;
- ◆ Gas release to lakes; and,
- ◆ Doses to NHB (including both generic and interest species).

Current work is focussed on landscape modelling for KBS-3H evolution with doses being assessed for a period of 10,000 years, as defined by the Finnish regulator. The landscape model is comprised of 75 different areas that are defined as coastal, forest, mire, river or 'super-lake' areas. Preliminary results for I-129 have predicted maximum concentrations, of around $7E-11$, to occur in forests as a result of a 1 Bq/y release to the biosphere. Release points to the biosphere have been adopted from the TILA-99 assessment (given static areas for three time points assumed to move at constant rate with time), but variants will be calculated for release points predicted on e.g. the basis of bedrock fracture locations and frequency.

Work is also progressing on a Knowledge Quality Assessment, which takes account various aspects of the assessment including:

- ◆ Completeness of consideration of processes;
- ◆ Pedigree analysis;
- ◆ Consistency and confidence assessment;
- ◆ Numerical sensitivity and uncertainty analysis; and,
- ◆ Relative importance.

Once the pedigree analysis is completed, it is intended that the average score against sensitivity index will be plotted to identify the most sensitive parameters for which further work may be advised in order to increase confidence in the assessment. Increasing assessment confidence is one of the main challenges currently faced by Posiva. Ari concluded by raising a number of areas for which collaborative tasks may be beneficial:

- ◆ conducting a knowledge quality assessment for NHB assessments through a sensitivity analysis and pedigree scoring campaign;
- ◆ development of radionuclide transport models that better represent ecological processes; and,

- ◆ a model validation programme to look at methodological aspects of assessments in relation to real ecosystems.

Much of the subsequent discussion focussed on the pedigree analysis approach that was considered by participants to be very useful in building confidence in the assessment. In particular, it was considered potentially useful as a means of communicating aspects of an assessment to stakeholders. However, the point was raised that it would be difficult to avoid prejudice when selecting experts for scoring of the analysis. In response, Maryla Wasiolek offered to make available the US procedure for expert elicitation, which is a formal process that is conducted under quality assurance procedures. Mike Thorne also introduced the method being considered by the UK NDA (RWMD) in which seed questions are used to allow expert opinions to be ranked.

3.3 Yucca Mountain Project

Maryla Wasiolek provided an overview of progress at Yucca Mountain over the last year. In the US a licensing rule is awaited that will provide the dose standard against which the repository performance should be assessed. A standard had been available previously, but this had a 10,000 year timeframe associated with it and was therefore not consistent with National Academy recommendations. A draft rule has been prepared which takes account of the timeframe issue. It provides two dose standards, one that should be applied for periods up to 10,000 years and a second for the period of geological stability. However, there has been a lot of opposition to this and no final decision has been made.

The application to construct the repository at Yucca Mountain is being prepared at present and is due to be submitted mid-2008. The best achievable timeframe for the opening of the repository is 2017. However, the repository should have been made available by 1998. The delay has resulted in a number of law suits in the US due to the continued need to store waste until the repository becomes available and this is increasing pressure on the US DoE to move forward with repository construction.

Modelling for the performance assessment is based on an agricultural well scenario using a total system performance model. The overall biosphere model is similar to that presented at past workshops; however some minor changes have been made to parameters such as irrigation period to increase realism in relation to actual agricultural practise. Enhancement factors for the resuspension pathway have also been revised through consideration of the particle size distribution of suspended sediment under different scenarios.

Discussion focussed on the transport of particles in air with Mike Thorne indicating the importance of considering the relative transportability of different sized particles. Frits van Dorp also noted that different particle types would differ in their behaviour with clay particles being less likely to be suspended in air that silt due to the formation of clay-complexes.

3.4 ReCLAIM – Assessment Tool for Contaminated Land

Mark Willans provided a demonstration of ReCLAIM, an electronic spreadsheet tool which was developed by Nexia Solutions. The tool calculates doses to exposure groups for assessment of radioactively contaminated land on an individual exposure pathway basis and on a multiple exposure pathway basis constituting various specifiable scenarios. It also calculates soil/water screening levels of individual

radionuclides with reference to selected exposure pathways and a dose target, and considers radionuclide additivity. The model does not distinguish between soil types, but can take account of depth of contamination.

The model is available for download from the Nexia Solutions website (www.nexasolutions.com/reclaim) and a paper summarising the model has been published in the Journal of Radiological Protection.

Mark also provided an update on the Low Level Waste Repository (LLWR) near Drigg in the UK. An authorisation for the LLWR was granted in May 2006, which has resulted in a requirement for issues raised on the previous post-closure safety assessment to be addressed. An environmental safety case is required to be produced in 5 years time which is to include revised operational and post-closure safety cases.

3.5 Assessment Biosphere Management System (ABMS)

Keiichiro Wakasugi provided an overview of developments in Japan and introduced the Assessment Biosphere Management System (AMBS).

The AMBS is designed to manage all information relating to the assessment of the biosphere in relation to repository performance. The system is based on the IAEA's Reference Biosphere methodology and contains functions for inputting and managing all information relating to the system, including all models and parameters, the assessment context, background information and references. In addition, the full history of assessment can be stored to enable transparency in assessment. AMBS is a web-based system so is readily accessible.

The siting of a repository in Japan involves three stages. Firstly, following the selection of a volunteer candidate site, a literature survey is to be undertaken to gain information on the area. This is followed by a study of the geological stability at the site and finally an underground investigation facility is to be constructed. The selection of a site however has been problematic. In March 2006 an application was submitted to NUMO for a candidate site at Toyo town, which lies 500 km to the west of Tokyo. However, this was withdrawn on the basis that residents had not been consulted. Subsequently a number of meetings were held with residents and a new submission was made in January 2007 and in February 2007 Toyo town was informed by NUMO that geological conditions were suitable. Recently, however, the application has been withdrawn once more due to local objections to the siting and the election of a new mayor at Toyo town. Volunteer sites continue to be invited for possible evaluation.

Once a site has been selected, information from site investigations, strategy development and assessment context will be entered into the AMBS. It is intended that the system will be developed to integrate with other systems such as a geosphere assessment system.

3.6 SR-Can

Developments on the SR-Can assessment for the Swedish repository were presented by Tobias Lindborg, Sten Berglund and Ulrik Kautsky. SR-Can is a safety assessment exercise that aims to demonstrate the overall safety assessment methodology and to evaluate usability of the site data (is more required) and whether the conceptual understanding of the site and resultant models are adequate. Two sites are being investigated, both of which are located in east Sweden; Forsmark is located to the

north of Stockholm and Laxemar to the south. SR-Can is available from the SKB website (www.skb.se).

Tobias began by providing an overview of the Landscape model within SR-Can. An initial safety case assessment was submitted Autumn 2006 and is undergoing review. A verdict by the authorities is due in December 2007.

For modelling purposes, the landscape has been divided into different ecosystem types that are linked through surface hydrology. Discharge points into the biosphere have been determined on the basis of flow paths through the bedrock and these have been used to focus site characterisation programmes. Exit points are in general clustered. Landscape modelling is being conducted within the Pandora tool.

Landscape evolution has been taken into account (for example the evolution of lakes to agricultural land) in a stepwise approach. Current biosphere objects are described in timesteps from marine to freshwaters to mire to terrestrial land. Initially a shoreline displacement model has been used to determine whether objects will be above or below sea level. For objects occurring above sea level, a future lake model is used to determine (on the basis of topology) whether a lake will form or whether the area will be terrestrial land etc. sedimentation rates are employed to predict how long surface water features such as lakes remain before evolution to terrestrial land. To ensure conservative assessments, the model is forced to make agricultural areas from terrestrial land wherever possible. Where land is not suitable, the model assumes this to be forest.

Following the landscape model description, Ulrik continued by describing the landscape dose factor approach and providing a summary of results from the SR-Can dose assessment.

Future human behaviour is unknown and therefore dose estimates have been based on carbon intake requirements for a reference man in combination with knowledge on food production rates of current ecosystems. By taking such an approach, assumptions as to future diets can be avoided. The ecosystem production and carbon intake approach has also been used to estimate the size of the most exposed population through consideration of how many persons can be sustained by biosphere objects and can be used to determine whether food must also be obtained from outside of a single object. The approach is considered to be defensible as it is based on science; dose is connected with human resources. The maximum dose calculated was for a mire. However, only half a person could be sustained by this ecosystem due to the low productivity.

A conservative approach has been employed in relation to the behaviour of radionuclides. Since the concentrations of radionuclides vary with time, for the purposes of the dose assessment, maximum concentrations, irrespective of time, were employed. The movement of radionuclides between biosphere objects has been based on a mass balance approach; where radionuclides leave one biosphere object they are assumed to enter another.

There is a regulatory requirement to calculate dose to the most exposed population. To calculate this, the population has been assumed to include the most exposed person plus those receiving more than one tenth of the most exposed dose. Individuals are assumed to remain within one biosphere object to ensure conservative dose estimation. This approach has been used as the basis for calculating landscape dose factors, which are the average of these dose predictions.

A number of different scenarios in relation to the release of radionuclides from the repository have been considered in SR-Can. These have included growing pinhole copper corrosion, shear movement and isostatic collapse as a result of high ice-load. For some of these scenarios, the regulatory limits were breached, but this occurred after 10,000 years. The regulatory criteria require dose to humans to be considered up to 10,000 years.

A non-human biota (NHB) assessment has also been conducted using the EC ERICA assessment tool. Overall the tool was considered difficult to apply to the SR-Can scenario and fundamental data were found to be lacking and/or pessimistic. The ERICA assessment tool provides a tiered approach and, for some radionuclides the risk quotient was breached in application of the initial tiers. Concern was therefore raised as to how a failure at the lower tiers, but pass at higher tiers, should be communicated to stakeholders. Unlike human dose assessments, in Sweden there is no time constraint on the calculation of dose to NHB. Therefore, up to 10,000 years human doses define compliance status, but after this period the compliance status is defined by dose to NHB.

Following the overview of SR-Can dose assessments, Sten presented the SKB approach to the modelling of the GBIZ (geosphere biosphere interface zone). Exit points from the geosphere to the biosphere tend to be located in low lying areas such as valleys and lakes and, therefore, these are the areas for which site characterisation efforts should be focused.

Flow paths and exit points have been predicted using deep rock hydrogeological models. Radionuclide retention is then assessed using biosphere dose models. The accuracy of predictions from large scale models has been assessed by comparison of predicted exit points from surface and deep rock models. Both models agreed well. However, one area of uncertainty relates to the rock type present at Forsmark, which contains shallowly dipping deformation zones of high permeability. This may result in surface rocks acting as a sink for water rather than being a discharge regime. A comparison of transport scenarios is therefore being undertaken.

Work at present is focused on updating models (hydro-geological conceptual, numerical flow and transport models) on the basis of the most recent site data.

3.7 ANDRA Challenges

Elisabeth Leclerc provided a presentation on the current challenges faced by ANDRA in relation to their radioactive waste management programme. It is a requirement in France that the reversibility of the site be demonstrated.

The French site for geological disposal of radioactive waste is an inland site to the east of the country. As such, only agricultural dose pathways require consideration. The site has a well characterised simple geology with a defined transposition zone.

In 2005 a feasibility study was completed, which demonstrated that geological disposal was feasible in France and, in 2006, dates were specified in relation to the progression of the repository. An Environmental Impact Assessment report is due for submission in 2014 with construction beginning in 2017. The first waste should be emplaced in 2025. For the EIA report further geosphere characterisation will be required and underground experiments will be conducted in an underground research laboratory.

A surface monitoring programme is about to be conducted for site characterisation. The site is simple, comprising mainly forest with some agricultural and grassland areas in valleys. Previous work on site characterisation did not include forest areas and, therefore, this will be a main focus of the surface monitoring programme and will include consideration of element cycling within the forest areas. Some transfer experiments may be required to gain data on translocation.

The surface monitoring programme will involve the collection and banking of samples (soil, water, biota etc.), which will be supported by a database with GIS parameters that is under development. The production of this sample bank is considered as one of the main challenges faced at present. The bank will be constructed on the site and foodchain samples will be prioritised. The purpose of the banking of samples is to ensure additional analyses can be conducted as methods become available and to demonstrate impact of the repository on the basis of pre-repository measurements.

Selenium is considered an important radionuclide for the site and model development for this radionuclide is, therefore, planned for which transfer parameters will be required. There is also a need to consider different climate predictions including a new warmer scenario that has not previously been considered and hence forms a new challenge for ANDRA. ANDRA are also responsible for a graphite disposal project and for conducting a monitoring programme around a closed disposal site.

3.8 NDA Modelling Studies

Mike Thorne presented on behalf of the NDA (RWMD). The presentation focused on point-scale model developments by Imperial College, London. In addition, particular priorities for the NDA (RWMD) were noted. These include:

- ◆ CI-36 due to its content in graphite within ILW;
- ◆ the gas pathway (particularly in relation to C-14); and,
- ◆ catchment-scale modelling for which a review of available techniques is envisaged that would look to compare different systems.

Imperial College has developed a 1-D transport model for the uptake of radionuclides into plants over the long-term. Simulations of Cs migration in soil over a 50-year period have been conducted and compared with soil profiles and hydrological data from Silwood Park. The model predicted a peak in Cs below the soil surface, but the actual profile showed an exponential decrease from the surface. However, when bioturbation was taken into account as an effective diffusion process, the model predictions were improved. A similar effect to that of bioturbation was achieved by assuming strong root uptake and subsequent loss through the leaves, which results in a new injection at the surface soil as a result of leaf loss and deposition at the soil surface. It is therefore difficult to determine which of these processes (bioturbation or root uptake) is the dominant process. However, based on experimental and field data, bioturbation is considered to be the more likely to be dominant. It is intended that the model will be further developed in 2007 to include deep rooting.

The data available from Silwood Park (Cs in soil profiles, root density profiles, meteorological data including precipitation and evapotranspiration (based on the PENSE record) could be used for model testing purposes. However, some reconstruction of Cs concentrations in rainfall has been required on the basis of air concentration data.

In addition to the soil-plant transport model, experiments have been conducted by Imperial College to investigate the sorption of iodine under different hydrological conditions with time using soil mini-columns. Results have indicated that for more saturated soils, the Eh reduces after around 20 days as a result of reduction of oxygenated conditions. In reducing conditions, Kd was not found to increase as it does when soils remain oxygenated. A model for iodine advection-diffusion has been developed with redox changes simulated on the basis of oxygen advection-diffusion with most parameters being derived from former experimental work. The soil used in the experiments was sandy and, therefore, consideration is currently being given to whether or not results can be up-scaled for alternative soil types. A detailed theoretical study has been conducted on alternative approaches to upscaling and on whether point-scale models can be used to represent heterogeneous spatially extensive soil systems.

It is envisaged that the point-scale models will further enhanced and results obtained will be used in catchment-scale modelling for assessment purposes.

3.9 Update on progress in Switzerland

Frits van Dorp (Nagra) briefly explained that, in Switzerland, site selection procedures are being defined by authorities. Once procedures are available, progress will be made to select sites for both high level waste and intermediate/low level waste.

4. CONTINUING WORK PROGRAMME

4.1 Chlorine-36 Accumulation in Soil and Crop Uptake

Following the international forum on Cl-36 held in September 2006, a task was initiated to compare models (traditional, specific activity and more detailed soil hydrology and crop interaction models) for the accumulation of Cl-36 in soil and uptake into crops. The intention of the task is to investigate:

- ◆ whether variation in peak dose predictions are a result of model structure;
- ◆ how much variation is inherent within all models;
- ◆ whether more advanced models improve predictions; and,
- ◆ whether more data are required and, if so, whether this can be achieved through research or whether better site is required.

The objectives are to compare the scientific basis for the modelling of Cl-36, to conduct illustrative calculations and to make recommendations for better dose estimation methods or for improved data collection.

Two scenarios are being considered, one considering agricultural soil contamination as a result of irrigation with unit activity concentrations in water and the second assuming contamination of agricultural soil from below (i.e. groundwater). Concentrations in maize, potato and lettuce in a typical year and upper estimates are to be predicted and reasons for upper estimates (i.e. factors chosen) to be provided.

A session was therefore held during the workshop to allow participants in the task to present their modelling approaches and preliminary results where applicable. Current participants include EDF, ANDRA, OPG, JGC, Mike Thorne (for NDA (RWMD) and CIEMAT), and Enviro (using EPRI and BIOMASS models). Other participants are invited.

Different models are initially being applied for different sites and locations and, therefore, results are expected to be variable. It is intended that the task will be reported on in 2007 and there will be a group responsibility for the collation and analysis of results and preparation of the report.

4.1.1 Cl-36 model for L/ILW Disposal in Japan

Kunihiro Nakai began by explaining that, in Japan, Cl-36 is considered a priority radionuclide in relation to LLW and ILW due to its rapid release from graphite, its low sorption to natural and engineered barriers and high sorption to organic matter and uptake into fish and crops. Exposure pathways considered in relation to Cl-36 are primarily associated with river water, but well water pathways are also considered.

For dose calculations, a rapid fractional release of Cl-36 is assumed (of the order $2E-4$ to $2E-7$ per year). A 1-D advection model is used for the migration of Cl-36 in groundwater. A low K_d and fast migration into surface waters are assumed and dilution within a river or brackish lake is taken into account with subsequent application to agricultural land (at which point high K_d ($27 \text{ m}^3/\text{kg}$) and concentration factors are assumed). Both rainfall and evaporation are considered. Dose estimates

for a 1 Bq/y release were in the order of 1E-4 to 1E-5 mSv/y based on consumption assumptions derived from Japanese statistical data.

There are a number of uncertainties associated with the modelling of Cl-36 including:

- ◆ The chlorine content of activated materials;
- ◆ Release rate;
- ◆ Sorption to barriers; and,
- ◆ Sorption to organic or farming soils.

In discussion, Mike Thorne questioned the use of the high Kd value of 27 m³/kg. It was explained that this value was selected due to a lack of specific data for Cl-36 and resultant use of a chemical analogue. It is intended that this value will be revised as more data on Cl-36 become available.

4.1.2 EPRI Model

Graham Smith presented the Cl-36 model used in EPRI assessments for Yucca Mountain. The EPRI model takes account of irrigation of soil, leaching, and uptake by plants. Upwelling of ground water is not considered due to the model being developed for desert conditions at a location where the water table is at least 50 m deep. For plant contamination both root uptake and soil splash are considered, but soil splash is subsequently removed as a result of food processing assumptions. Due to desert conditions, a high irrigation rate is assumed.

The main uncertainty with the model is the concentration factors (CF) applied. A CF of 1 results in a food concentration of 1.6 Bq/kg, a CF of 5 results in a concentration of 7.9 Bq/kg and a CF of 100 leads to a concentration of 110 Bq/kg. Cropping processes result in reduced soil concentrations at higher CFs and, therefore, increasing the CF above 100 has a limited effect on dose unless it is assumed that plant matter is returned to the soil following cropping.

4.1.3 BIOMASS Reference Biosphere Model

Graham continued with a description of the BIOMASS Reference Biosphere model. This is a more complex model than that employed by EPRI in that it is designed to account for upwelling of groundwater in addition to contamination by irrigation water. Questions arise in the application of the model in relation to groundwater contamination, however, in that it is not known how much of the contamination will be leached and how much will enter surface soil.

Doses calculated using the BIOMASS model were around 5 times lower than those predicted from the EPRI model due to a reduced irrigation rate assumed in BIOMASS. However, climate assumptions and site characteristics can affect dose predictions as can variation in Cl-36 behaviour assumptions.

4.1.4 OPG Cl-36 Internal Dose Assessment Model

OPG have provided to BIOPROTA the basis for their specific activity model for Cl-36 uptake to crops from soil. It involves calculating the dose according to Kd and CR assumptions, and then determining, based on natural levels of chlorine in soils and crops at the site of interest, whether such a dose estimates implies concentration of

Cl-36 in chlorine. If so, the dose is reduced to the level at which at least Cl-36 is only replacing stable chlorine. This is a robust approach, but uncertainties arise concerning identification of the relevant average stable chlorine levels over appropriate temporal and spatial scales.

4.1.5 Results from the NDA (RWMD) Model

Mike Thorne presented the model and initial results on behalf of the NDA. The full Cl-36 model was described previously and is reported in the Cl-36 workshop report available on the BIOPROTA website (www.bioprota.com). However, the model has subsequently been updated to include organic Cl-36 on the basis of data reported at the workshop. Two reports on the Cl-36 model will be available shortly on the NDA (RWMD) Bibliography. The first provides a full description of the model. The second details a sensitivity study.

The model includes water flow in soils using a two-layer model and accounts for water uptake by plants, stable chlorine concentrations, transpiration, passive and active uptake of chlorine and passive back diffusion from the plant into soil. The model also accounts for the conversion between organic chlorine and chloride. Lateral losses are allowed if required. The model is comprised of three organic compartments that are each linked to an inorganic compartment.

Mike explained that plants have high internal concentrations of chloride and this therefore suggests active uptake in relation to soil. The downward movement of organic chlorine in soils is dominated by bioturbation.

For the irrigation scenario, an input of 1 Bq/l was required for irrigation water, but this has to be mixed with rain water for which 800 mm of precipitation was applied on the basis of average conditions within the UK. Therefore, only around 50 mm of irrigation water would be required. Similarly, rainwater must also be taken into account for the groundwater upwelling scenario. In this case, 0.1 m per year upwelling water was assumed in combination with the 800 mm precipitation. Lateral drainage from agricultural soils was unrealistically suppressed in the model to enable the scenario to be calculated as prescribed. The model was run to generate results from 1 to 10,000 years.

Results indicated that Cl-36 saturation in plants would be reached in around 10 years time and soil properties did not have a large effect on plant concentrations. However, in the topsoil and sub-soil, organic chlorine was found to take a long time to reach equilibrium. Overall, plant concentrations were found to remain the same, but soil concentrations increased substantially with time, which raises questions as to the suitability of using concentration factors in such assessments. The results of the assessment were not found to be sensitive to variations in soil sorption assumptions.

4.1.6 EdF Model Structure

Phillipe Ciffroy presented the model employed by EDF, which is based on a specific activity concept that includes a compartmental dynamic model to represent the chlorine dynamics in soil. The specific activity approach is based on the assumption that Cl-36 and stable chlorine are in equilibrium, so the ratio between these will remain the same both in the plant and within the environment in which it lives.

For uptake into the plant there are two main assumptions; chlorine is taken up from the soil and it follows the transpiration water. Ch-36 concentrations in plants, therefore, depend on the transpiration flux and the stable chlorine/Cl-36

concentrations in soil pore water. The transpiration flux is calculated taking into account solar radiation and temperature and actual transpiration is calculated from the evapotranspiration rate combined with the leaf area index, which is season dependant and thus varies with time.

Inputs to the model are rainfall and irrigation. Outputs are evaporation and percolation water. Three soil layers are considered with topsoil being the most important for plant uptake due to the root density in this depth range. Chlorine can be removed from the system either as a result of cropping or loss from subsoil.

4.2 Future Task Development

Further participants for the CI-36 task are invited. It is intended that the first set of calculations will be completed by the end of June/early July. Once completed, Mike Thorne will compile the results in a summary report. It is anticipated that a meeting will be held to enable discussion of this report, potentially in late August. Arrangements for the meeting (date and location) are to be arranged.

5. PARALLEL WORK PROGRAMMES

Three additional work programmes of relevance to the BIOPROTA programme were also presented and a brief overview of each of these is provided below.

5.1.1 IUR Task Force

Almudena Agüero provided an overview of the past, present and future work of the IUR Task Force on waste and radioecology. The task force began in 2002 with the objective to promote co-operation between radio-ecologists working in waste management. A report was produced by the task force in 2006 that provided recommendations for improving predictions of long-term environmental behaviour of key radionuclides. This report concluded that:

- ◆ Good models are available for C-14 and dose is strongly influenced by the degree of metabolism of methane in soil;
- ◆ For Cl-36, consideration should be given both to the incorporation into soil biota and to the input and output of stable chlorine;
- ◆ Chemical speciation largely dictates the behaviour of Tc-99 and data are limited for terrestrial transfer, particularly in relation to non-agricultural crops;
- ◆ More experimental work is required on Np-237 in relation to large animal metabolism and behaviour under anoxic conditions in lakes; and,
- ◆ There is a need to characterise mobility and uptake of U-238 and geochemical modelling should be employed for soil-plant transfer studies.

It is intended that the important processes for key radionuclides will be described in more detail and approaches to modelling will be proposed in future reports. The task group meets once per year, with the next meeting being held in October 2007.

5.1.2 EC PROTECT Project

A presentation was given by Karen Smith on behalf of Nick Beresford and Brenda Howard, CEH, on developments since January on the PROTECT project to which many of the BIOPROTA sponsoring organisations have contributed questionnaire responses.

The PROTECT project aims to evaluate the practicability and relative merits of different approaches to protection of the environment from ionising radiation and to compare these with methods used for non-radioactive contaminants. The intention is to provide a basis on which the EC could develop protection policies and revise its Basic Safety Standards. This is being achieved through consultation, via questionnaires, with both industry and regulators to review regulatory approaches to chemical and radioactive substances. The various approaches used internationally will be evaluated for their practicability, acceptability, relevance, usability and transparency. Following review of responses it is intended that recommendations will be made for generating common approaches to the protection of the environment and that numerical target values for an extended list of ecological targets and protection levels will be derived and proposed and their implications for society analysed.

Since the NHB forum in January/February 2007, the PROTECT consortium has largely focused on gaining questionnaire responses from regulators and industry. A meeting

was held in March that was specifically intended to elicit regulator views on protection of the environment in relation to:

- ◆ Justification for regulating the nuclear industry;
- ◆ Alignment of chemical and radioactive substances regulation;
- ◆ Appropriate targets for protection;
- ◆ Demonstration of compliance against protection goals;
- ◆ Credibility of currently suggested benchmark values for ionising radiation and appropriateness of methods used to derive them; and,
- ◆ Treatment of background exposure within assessments.

A report detailing the review of approaches to protection of the environment from chemicals and ionising radiation and requirements and recommendations for a common framework is due in November 2007. Further information on PROTECT is available from the project website (www.ceh.ac.uk/protect).

5.1.3 IAEA EMRAS – Progress of the TRS-364 Working Group

Elisabeth Leclerc provided an overview of the work of the IAEA EMRAS working group responsible for updating document TRS-364 on radiological transfer parameters, which began in 2003. The initial TRS-364 document was based on information available in literature up to 1990 and did not provide any recommendations on how the proposed values should be selected and applied. Therefore, the TRS-364 working group aims to propose revised transfer parameters and information relating to transfer processes. Parameters will be proposed on the basis of referenced values rather than expert judgement.

The group has reviewed available literature and are documenting transfer processes. The revised document will include new sections on modelling processes in rivers, rice culture, specific activity models for tritium, C-14 and Cl-36 and methods for applying analogues where data are lacking.

The work of the group will be published as a new IAEA technical document and will also be published in a special issue of the Journal of Environmental Radioactivity.

6. NEW TASKS AND FUTURE WORK PROGRAMME

A number of possible future tasks were outlined that may be of interest to the Forum. Participants are requested to consider whether they/their organisation would be interested in funding/participating in each of the tasks detailed below.

6.1 Towards a Consolidated and Integrated Data Set on Chlorine (Cl-36) Cycling in Forests

Yves Thiry presented a proposal for a study that aims to provide data on the cycling of chlorine in forests. Forests are important ecosystems in terms of their biomass production and turnover and can have a large impact on water cycling. Good forest process models are available that can account for the biomass and water cycling associated with these ecosystems, however, often there is a lack of data on which models can be based. A field study has therefore been implemented at Mol in Belgium that aims to derive an integrated data set on chlorine cycling in a forest.

The study site is comprised of an old Scots pine forest with a well developed understorey. The soil in the region is podzol (>92% sand) and the water table is variable depending on season.

A water cycling study has been completed at the site. The understorey was found to have a larger influence on water cycling than the pines, as a result of transpiration. During the growing season, the water table was found to contribute 26% of the water requirements of trees through capillary rise. However, this increased to 65 – 99% during drought periods.

Biomass samples were collected at the same time as water samples for chlorine cycle analysis. These have included different aged pine needles, branches, litter fall, understorey samples in addition to soil solution and groundwater samples. Test samples of these have been analysed to determine a preliminary chlorine budget.

It is proposed that a post-doctoral study could be initiated within the BIOPROTA programme. This would involve completion of sample treatment and analysis and data interpretation to fill data gaps relating to chlorine budget, including transfer across the GBIZ (defined as the zone between the minimum water table and unsaturated soil). Consideration could be given to the analysis of other elements of interest to the forum should funding be available.

ANDRA, SKB and Posiva all noted interest in this task and Yves was, therefore, tasked with moving the proposal forward. All interested participants are requested to review the proposal that was circulated prior to the workshop and submit any comments/suggestions to Yves who will then collate and amend the proposal where possible. Information on funding requirements and management are to be provided to interested participants.

6.2 Carbon-14

A proposal for a comparison of models for C-14 behaviour in the biosphere was circulated in June 2006 and interest in participation/funding was received from Nirex (now NDA (RWMD)), NAGRA, NRI and Posiva. This was considered a reasonable number of participants, however further funding would be required for reporting. It was agreed that Mike Thorne would distribute a case study for consideration by

participants. Participants are requested to provide feedback as to the relevance of the case study and whether amendments to the case study (or additional case studies) would be beneficial. Once feedback has been received, a revised proposal will be prepared and distributed to the sponsoring organisations and other potentially interested parties out with the forum inviting technical/financial support.

In addition, Mike Thorne explained that the NDA (RWMD) is considering supporting field experiments for the C-14 gas pathway. This would involve the use of a C-13 tracer and methane consumption rates and fate of products will be investigated. Should this experiment go ahead, it could provide useful input to a C-14 modelling task. Mike will, therefore, keep participants informed of progress.

6.3 Sensitivity Analysis of a Non-Human Biota Assessment Method

Ari Ikonen presented a proposal for a sensitivity analysis of the ERICA non-human biota assessment method. This would involve looking at the distribution of parameter values and correlations between parameters and identifying which parameters effect dose to the greatest degree. This would then help determine where further modelling or experimental work is required. The focus of the study would be on whether data distributions and application assumptions are relevant to waste repositories.

The analysis would focus on Tier 3 of the ERICA tool. It is proposed that two consultants would be involved, one with ERICA/NHB experience who would be responsible for data collation and reporting and a second with experience of sensitivity analysis. This could be followed by a joint pedigree scoring task.

In discussion, Mike Thorne raised the suggestion that a comparison of human and NHB dose could be undertaken on the basis of set environmental concentrations. This would help identify the constraining radionuclides and help prioritise future work. Several case studies are available that could be used as the basis of the assessment.

Ari agreed to lead the development of this task and will look to gain support from others outside of the forum where appropriate.

6.4 Site Characterisation

The Theme 3 report on site characterisation was completed in 2006 and it was always the plan that further tasks in this field would be initiated once the report had been completed. Graham Smith therefore put forward an idea for consideration on whether a coordinated programme could be instigated looking at the choice of parameter values such as Kd and CF and whether there are instances in which such values are common to a number of sites or whether they are very site specific. The task would be aimed at those organisations for which no specific site has yet been selected.

Elisabeth Leclerc raised the point that work of the EMRAS TRS-364 working group could be very useful in this respect as they have collated available information for a range of radionuclides and identified where data are lacking. This could provide a good starting point for a task of this nature.

It was therefore proposed that a task be undertaken to extract relevant data from the revision of TRS-364 and identify data gaps. The Theme 3 report would then be revised in light of the review of data availability.

Elisabeth requested that both Posiva and SKB assist in improving the Theme 3 document in light of their site characterisation experience.

6.5 Uranium Series Modelling

The idea for a task on U-238 series modelling was raised in May 2006 and a proposal for a task was distributed. Little feedback was received on this proposal, but there appeared to be continuing interest from forum members. Mike Thorne therefore raised two issues that could potentially be addressed through a combined task within the BIOPROTA forum. The first could look at modelling the way in which radionuclides (U-238 and daughters) decay and migrate following a long-term release. The second could look at how non-equilibrium in a soil-plant system could be addressed.

An idea for Rn-222 dose calculation in relation to inhalation and the gas pathway and whether this is being considered accurately in models was also raised. Mike noted that this is of particular interest to the NDA (RWMD) since bulk gas generation in a repository can result in Rn-222 stripping, depending on rock type. Graham noted during discussions that there is a lot of uncertainty associated with Rn-222 and this radionuclide is not largely being considered in PA. Where radium doses are included however, there may be a need to also consider dose from Rn-222.

It was agreed that Mark Willans would take this task proposal forward by updating and re-circulating the proposal distributed in 2006 and potentially updating following the receipt of feedback from interested participants.

6.6 Historic Discharge Analogues

Following the last Forum meeting in May 2006 a proposal was prepared on the use of anthropogenic analogues, but was not distributed. The proposal was to investigate the environmental behaviour of radionuclides through study of historical discharges and whether available data could inform estimates of the future dispersal of releases.

In discussion, it was suggested that it might be beneficial to review specific priority data needs with a view to then selecting potential analogue sites that could help address some of these data requirements.

6.7 Workshop on the Environmental Behaviour of Se-79

Frits van Dorp put forward an idea for a workshop to be held on the environmental behaviour of Se-79. This is one of the more critical radionuclides in intermediate/low level waste, and more information on its behaviour is required. The aim of the workshop would, therefore, be to identify the most important processes for this radionuclide.

The workshop would be open to BIOPROTA participants, but also to external contributors (including experts on stable selenium if possible). It is intended that the workshop would be hosted by NAGRA in 2008. Both Mike Thorne (on behalf of NDA (RWMD)) and Elisabeth Leclerc (ANDRA) noted their interest in such a forum.

6.8 Non-Radioactive Risks

The suggestion was made that non-radioactive risks from waste repositories could be investigated. For example, the NDA has recently conducted a review of this issue and beryllium was identified as being of relatively high importance. It was, therefore, agreed that EnviroS would distribute a questionnaire based on past identification of issues to identify which issues have been addressed and which still remain (and if any new issues have been identified). All participants are requested to provide input to this review of issues upon distribution of the questionnaire.

6.9 Sensitivity Analysis of Biosphere Parameters

Antonín Vokál noted the interest of NRI in a sensitivity analysis of biosphere parameters, particularly in relation to I-129 and C-14 and what impact these parameters have on dose (human and non-human). In discussion, Elisabeth Leclerc offered to provide the latest sensitivity analysis conducted by ANDRA to help inform on the main factors of concern. Other participants are also invited to provide similar analyses, where available, and NRI was invited to provide a review of differences in the important parameters between countries (where data supplied) at the next Forum meeting.

7. ADMINISTRATIVE ISSUES

At the close of the meeting, NRI were thanked for their efforts in organising and hosting the 9th BIOPROTA workshop.

7.1 2007/08 Forum Chair

Following the move of Ales Laciok from NRI to CEZ, a new Forum chair was invited. SKB has offered to provide the chair for 2007/08 if sponsoring organisations are in agreement.

7.2 2008 Forum meeting

The next BIOPROTA meeting (BIOPROTA X) is provisionally to be hosted by CIEMAT in Spain in the week commencing 5-9 May 2008.

7.3 Working reports

The use of a copyright disclaimer was suggested for working reports and the accessibility of such reports discussed. Envirois is to investigate the possibility of a members-only area for the website that could be used for draft documents. If such an area is possible, sponsoring organisations will be consulted to determine views on accessibility of reports outside of the Forum.

APPENDIX A: LIST OF PARTICIPANTS

Name	Organisation
Elisabeth Leclerc	Andra, France
Sophie Maillant	G2R/LSE for ANDRA, France
Ales Laciok	CEZ, Czech Republic
Philippe Ciffroy	EdF, France
Almudena Aguero	CIEMAT, Spain
Graham Smith	Enviros, UK
Karen Smith	Enviros, UK
Hideji Yoshida	JGC, Japan
Kunihiro Nakai	JGC, Japan
Mike Thorne	MTA, UK
Frits van Dorp	NAGRA, Switzerland
Matthais Brennwald	NAGRA, Switzerland
Mark Willans	Nexia Solutions, UK
Jiří Landa	NRI, Czech Republic
Antonín Vokál	NRI, Czech Republic
Václava Havlová	NRI, Czech Republic
Keiichiro Wakasugi	NUMO, Japan
Ari Ikonen	Posiva, Finland
Thomas Hjerpe	Saanio & Riekkola, Finland
Maryla Wasiolek	Sandia National Laboratories, USA
Yves Thiry	SCK.CEN, Belgium
Sten Berglund	SKB, Sweden
Tobias Lindborg	SKB, Sweden
Ulrik Kautsky	SKB, Sweden