BIOPROTA

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

Report of the Twelfth BIOPROTA Workshop

Stockholm, Sweden
24-27 May 2010

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23 July 2010

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.com.

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 2010 BIOPROTA workshop, hosted by SKB in Stockholm, Sweden, from 24th to 27th May.

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 RPS P&D and GMS Abingdon following the workshop and distributed 30 June 2010.

Version 2.0: Report prepared by RPS P&D and GMS Abingdon in light of comments received on version 1.0 report and distributed 23 July 2010.

CONTENTS

1. INTRODUCTION

The twelfth BIOPROTA workshop was hosted by SKB in Stockholm, Sweden on 24-27 May 2010. This report provides a record of the presentations made and resultant discussions during the workshop. An overview of the field trip to Forsmark, arranged by SKB, is also provided.

The support of SKB in the organisation and hosting of the workshop and the Forsmark field trip is gratefully acknowledged. The work of Posiva in the organisation of the optional field trip to Olkiluoto is also gratefully acknowledged.

1.1 CURRENT SPONSORS OF THE BIOPROTA COLLABORATIVE FORUM

Currently there are 18 sponsors of the International BIOPROTA collaborative forum:

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

1.2 OBJECTIVES OF THE TWELFTH WORKSHOP

The objectives of the workshop were to update interested parties on progress since the last meeting in May 2009 on the various activities and projects 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.

1.3 PARTICIPATION

The workshop was attended by 29 participants from 11 countries, representing a range of operators, regulators and technical support organisations. Participants are listed in Appendix A.

1.4 REPORT STRUCTURE

The remainder of this report provides:

- An overview of progress made in 2009/10 (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 the field trip to SKB's Forsmark site (Section 5);
- An overview of the forward BIOPROTA programme for 2010/11 and summary of participant interest areas (Section 6); and,
- Forum administrative issues (Section 7).

1.5 ACKNOWLEDGEMENT

Participants expressed their appreciation to SKB for hosting the event and especially to SKB staff for their work in preparing both for the forum meeting and the site visit to Forsmark.

2. PROGRESS IN 2009/10 OF ESTABLISHED BIOPROTA WORK PROGRAMMES

A number of projects have progressed in 2009/10 including completion of Phase I of the C-14 long-term dose assessment project (and initiation of phase 2, discussed in Section 6.2), phase I of the Se-79 project on the transfer from soils to plants and phase 2 of the Cl-36 project on dose assessment and uncertainties. The non-human biota sensitivity analysis and knowledge quality assessment has also progressed and is nearing completion. A workshop was also held on the behaviour of radium in the biosphere for which a draft report has been issued.

An overview of each of these projects is provided below.

2.1 C-14 LONG-TERM DOSE ASSESSMENT (PHASE 1)

Laura Limer presented.

Phase I of the C-14 long-term dose assessment project was completed in December 2009 with the publication of an internal BIOPROTA report. The aims of the project were to improve confidence in long-term assessments of C-14 in safety cases through consideration of the effects of different approaches to modelling release scenarios and processes on model predictions and to consider where site specific information is necessary for applying different modelling approaches. The particular focus was on modelling C-14 in soils and uptake into plants, including representation of the plant canopy atmosphere.

Four organisations participated in the project – Andra, EdF, NDA (RWMD) and SSM. The models employed were[a]:

- AquaC14 (Andra);
- SA_carbon14 (EdF);
- Enhanced RIMERS (NDA (RWMD)); and
- The SKB-Posiva model (SSM).

The assessment scenario assumed a unit activity concentration in groundwater that is used for irrigation of agricultural land. Stable carbon concentrations in groundwater were fixed. It was acknowledged that C-14 release in gaseous form from a repository may be important; however, such a pathway was not the focus of the current project. A range of crops was selected and the evaluation was based on the part of the plant consumed. These crops were consistent with those considered in the BIOPROTA Cl-36 projects.

The processes implicitly and explicitly included in the models were investigated, including the way in which air exchanges between the plant canopy and the above-canopy atmosphere was represented. Initially the AquaC14 model emphasised direct foliar uptake. However, arguments for the amount of uptake changed during the project, thus parameters were adjusted within the model.

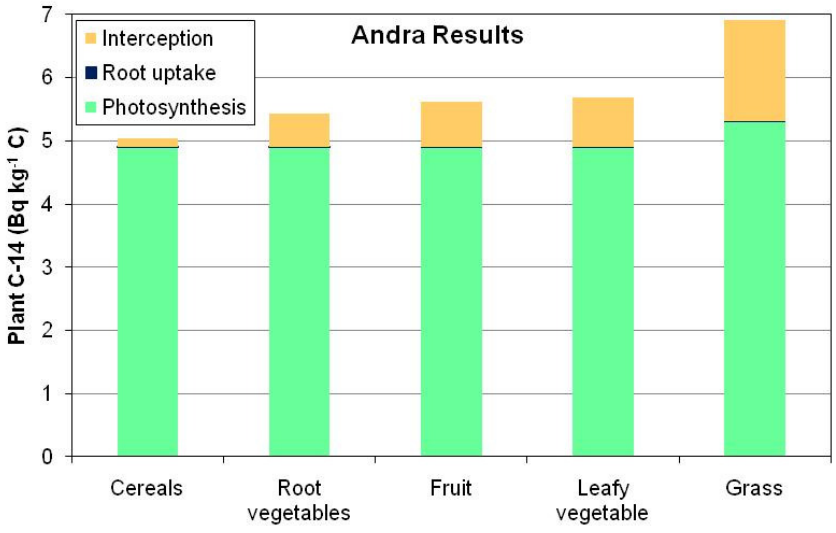
A number of questions were posed on the dynamics of the system such as:

[a] It is important to note that the models used in the study do not necessarily represent those currently used by the organisations – since the completion of the project, further models have become available.

- whether C-14 in water is input directly to soils from irrigation or whether leaf drip also contributes;
- whether the turnover of C-14 in soil is dependent upon organic matter content;
- whether root uptake is an important process in relation to C-14;
- whether microbial activity in soils is of importance (e.g. conversion of methane to carbon dioxide);
- the importance of degassing and volatilisation from soils in relation to the C-14 content of the canopy atmosphere; and
- which are the important loss mechanisms and influencing factors, such as the openness of the plant canopy and its effect on C-14 exchange with the above-canopy atmosphere.

With regard to root uptake, historical literature supports the theory that some C-14 may enter a plant via this route. Should leaves only see the immediate local atmosphere surrounding the leaf surface then the volatilisation of C-14 in water from the leaf surface may be an important pathway that could result in higher uptake.

Not all models considered root uptake thus results did not always include predictions of soil concentrations. For those models that did consider soil concentrations, the fractionation of carbon between forms of organic matter were within a factor of three in sensitivity studies. Results from the Andra AquaC14 model (below) indicate that root uptake is an insignificant pathway, accounting for only 2% of the total plant uptake of C-14. These results, which are in line with published literature data, help to support the exclusion of this pathway in other models.



For the plant canopy atmosphere, model predictions of C-14 concentrations differed by 3 orders of magnitude. However, a sensitivity study conducted using the enhanced RIMERS model suggests that results for this model could be an order of magnitude higher or lower depending on the canopy openness assumptions employed. The main factors affecting C-14 concentrations in the canopy atmosphere relates to the height of the stable layer (zero displacement height) in relation to the height of the canopy and whether the canopy is open or closed. The Posiva-SKB model assumes an open

canopy with a large degree of air exchange between the canopy and the above-canopy atmosphere; thus much lower plant concentrations (by 3 orders of magnitude) were calculated when compared with the other models employed.

The project identified a number of issues worth further consideration:

- Uptake of C (and hence C-14) via root uptake is likely to be a small proportion of total C uptake, but it is not clear how mall. If the concentration of C-14 in C in soil water is higher than in the canopy atmosphere, this small proportion may be important.
- How can the concentration of C-14 in the canopy atmosphere be assessed, bearing in mind the variety of different canopy structures that will arise for different crop types and changes during the season of the year and in the growing season?
- Does the stomatal atmosphere matter more for C-14 uptake than the wider atmosphere and, if so, does C-14 in water intercepted by leaves contribute to plant uptake?
- Is it possible to improve models based on knowledge of the fundamental biology/physics of the system (e.g. micrometeorological research on carbon uptake by photosynthesis)?
- Could inert tracers, such as noble gases, be used to estimate the relative contribution from soil atmosphere, plant-canopy atmosphere and above-canopy atmosphere?
- What would be the important (differentiating) factors to be considered when modelling C-14 uptake in non-agricultural ecosystems (for example, can we learn from literature on carbon cycling in forests)?

Discussion

It was agreed that the main source and process of carbon assimilation by plants is via photosynthesis. However, it can be difficult to differentiate between root uptake and translocation of carbon compounds by other uptake routes.

Photosynthesis will largely occur on sunny days which will coincide with pronounced vertical movement of air leading to a greater exchange with the above-canopy atmosphere, leading to a large diluting effect on C-14 in the canopy atmosphere. Since photosynthesis is the main pathway of importance and results for this pathway alone showed a large degree of variation, approaches to improving models further should focus on this pathway. In particular there is a need to focus on the period in which photosynthesis occurs, i.e. the period from 1-2 hours after sunrise to around 1 hour prior to sunset. The photosynthetic period would thus change with season and would be a site specific consideration.

Overall the project highlighted the fact that all the models employed represented potentially inadequate descriptions of the system. It was suggested that there is a need to move to a model which can capture the changing horizontal velocity of air as it rises vertically through the canopy. This changing velocity with distance above the soil surface affects turbulence and, hence dilution with the above-canopy atmosphere. The use of such a model would be of benefit in identifying key improvements in the parameterisation and/or conceptualisation of simpler models.

Noble gases were not considered to be appropriate as tracers for C-14 since carbon dioxide is a reactive gas for which the plant canopy is a sink.

2.2 NON-HUMAN BIOTA DOSE ASSESSMENT: SENSITIVITY ANALYSIS AND KNOWLEDGE QUALITY ASSESSMENT

Karen Smith presented.

The objective of the project was to investigate the overall uncertainties associated with non-human biota (NHB) dose assessments for radioactive waste disposal facilities, since it is considered that the below-ground source of radionuclides could affect the way in which assessments are undertaken. Consideration was given only to uncertainties associated with the transport of radionuclides from biosphere compartments (soil, water, sediment etc.) to biota. Uncertainties relating to the migration of radionuclides within the geosphere were excluded.

From the investigation the intention was to develop guidance for those undertaking post closure safety assessments for radioactive waste disposal facilities, particularly in relation to the important factors to consider when moving from site-generic to site-specific assessments.

The project was funded by Posiva, SKB, NRPA and Andra. Input data were supplied by Posiva and NDA (RWMD). The current status of the project is that a working draft of the report has been produced by Enviros Consulting Ltd in collaboration with Facilia AB.

The project had two key aspects: a sensitivity analysis, which focused on the quantitative uncertainties associated with NHB assessments, i.e. the sensitivity of the assessment output to changes in parameter values; and a knowledge quality assessment, which aimed to identify and assess the more qualitative uncertainties such as the degree of acceptability associated with the application of models and data.

The ERICA assessment approach was implemented within the EIKOS sensitivity analysis software. Assessment parameters, upon which the sensitivity analysis focused, were obtained from databases underlying the ERICA assessment tool and included:

- Distribution coefficients (Kd);
- Concentration ratio (CR);
- Weighting factor (alpha radiation); and,
- Dose conversion coefficients (DCC).

For the latter case (DCC), only single values are provided within the ERICA databases, but ranges were required for the assessment. As such, a review of biota geometries and masses was undertaken for the types of plant or animal represented by the default reference organisms and the ERICA tool 'add organism' functionality was used to calculate an appropriate range of DCC values for the analysis.

For the sensitivity analysis, three concept-specific test cases were considered:

- Terrestrial ecosystem, site generic assessment (NDA (RWMD) environmental concentration input data);
- Terrestrial ecosystem, site-specific assessment (Posiva environmental concentration input data); and,
- Freshwater ecosystem, site-specific assessment (Posiva environmental concentration input data).

A generic (unit release) case was also run with the objectives of identifying generic issues and pitfalls in the application of the ERICA methodology to radioactive waste disposal scenarios and developing a baseline understanding of assessment data gaps and uncertainties. The presentation focused on the results of the concept-specific test cases; it is important to note that the uncertainties highlighted relate specifically to these test cases and would be affected by alternative release assumptions.

Results of the freshwater ecosystem test case indicated that the main parameter influencing model output was the CR for C-14. A linear monotonic relationship was observed between assessment parameters and total doses (i.e. the majority of the variance can be explained by the direct effects of parameters on predictions). Only 5-10% of uncertainty could not be accounted for by consideration of the direct effect of parameters.

The terrestrial site-specific assessment indicated that CR was again the most important parameter; with DCC for external beta/gamma radiation also affecting the assessment output (up to 20% of the uncertainty relating to Cl-36 could be assigned to this parameter for the detritivorous invertebrate and soil invertebrate reference organisms). The interaction between parameters was important for some radionuclides. The key radionuclides contributing to total dose were Cl-36 and I-129.

For the terrestrial site-generic test case, the key parameters were CR for Np-237, Po-210 and Ra-226 and the alpha radiation weighting factor.

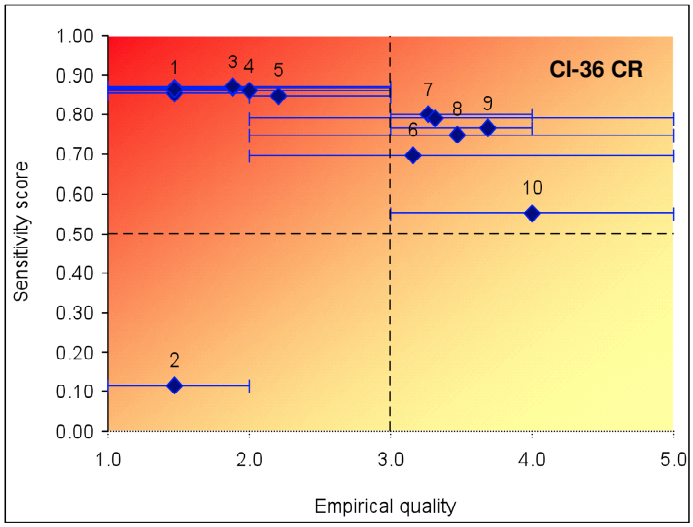
The knowledge quality assessment (KQA) was aimed at assessing the relative strength of data on the basis of background history of the data and the underpinning scientific status. A questionnaire was developed to elicit expert opinion on quality of models and data from the ERICA assessment approach. Responses (around 15 per question) were collated and average views and range of consensus were determined.

Overall, reasonable consensus was achieved for most questions posed and average scores indicated data / approaches were acceptable (or better). However, some specific issues were raised:

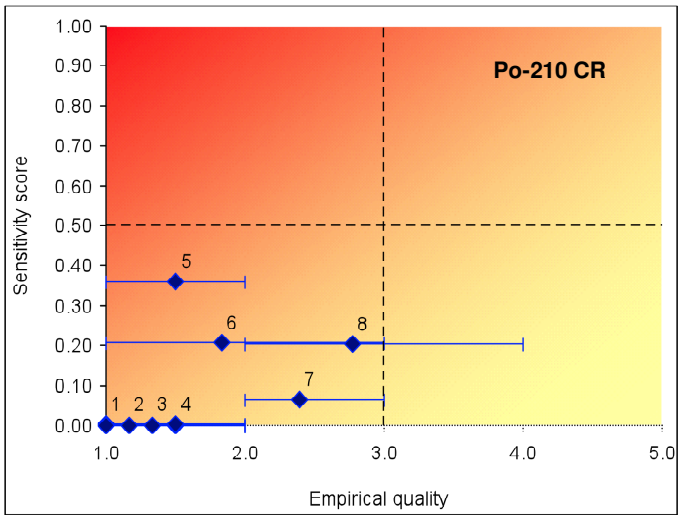
- There is a general lack of consideration of different life stages;
- Definition of “individual” questioned in relation to colonies and plants (e.g. what constitutes an individual grass?);
- Burrowing animals are not adequately represented in relation to terrestrial ecosystem assessments for radioactive waste disposal facilities;
- Occupancy factors were not always considered appropriate (for example, default values give maximum exposure, but this may not be appropriate were best estimate doses are required, default values may also not be appropriate in all cases for the types of scenario being considered for performance assessments);
- Some organisms are not appropriately represented for this type of assessment (e.g. trees are represented by the trunk, however roots may be maximally exposed (and contain more sensitive tissues) for such assessments; and,
- Empirical data for concentration ratios are largely available for human food chain organisms rather than key species of interest, thus analogue approaches are required. This is particularly the case for Np-237, for which Am-241 is often used as an analogue. As such, low scores were obtained in relation to empirical quality. Low scores were also obtained for the

empirical quality of CR's for Tc-99 in the terrestrial ecosystem and C-14, Cl-36, Ni-59, and Nb-94 in the freshwater ecosystem.

Combining the results of the sensitivity analysis with those from the KQA allows the key uncertainties to be identified – those for which there is least certainty (1 is low quality and 5 is high quality) and which affect the assessment output to a significant degree (sensitivity score toward 1). The results for empirical quality of concentration ratios for Cl-36 and Po-210 are shown below for comparison.



1 Amphibian, Bird, Reptile
2 Bird egg
3 Mammal (Deer & Rat)
4 Flying insects
5 Lichen & bryophytes
6 Soil Invertebrate (worm)
7 Tree, Gastropod
8 Detritivorous invertebrate
9 Grasses & Herbs
10 Shrub



1 Bird, Amphibian, Bird egg, Detritivorous invertebrate, Gastropod
2 Reptile
3 Flying insect
4 Mammal (Deer), Soil invertebrate, Mammal (Rat)
5 Lichen & bryophyte
6 Tree
7 Shrub
8 Grasses & Herbs

In the development of guidance, it has been noted that post closure safety assessments are largely based upon a well abstraction and irrigation scenario, which may not be the most appropriate for NHB assessments. Biota may be exposed to a greater degree from point source releases from geological fracture zones. However, this is unlikely to result in population impacts unless sensitive (i.e. rare / endangered) species are present.

Related to this is the issue of land rise assumptions. Generally the assumption is made that there is a transition to agricultural land during land rise predictions, which may not be a conservative

assumption in relation to NHB assessments. It has also been recommended that consideration be given in terrestrial assessments to soil dwelling organisms rather than the default organisms, selected on the basis of exposure from conventional (aerial) releases.

Concentration ratios have the greatest potential to dominate total dose uncertainty due to the range in values (3 orders of magnitude range is often observed) and there is a need to understand what drives these data ranges. Such understanding may allow for judgement as to the appropriate choice of CR under different scenarios and could also help target site characterisation studies where the important factors are understood. Concentration ratios should therefore be considered in moving from generic to site-specific assessments. This is particularly the case where soils are organic or where semi-natural systems are being considered – many of the default CR values are from mineral and agricultural soils.

A question remains as to whether generic CR's are more appropriate than site-specific values for performance assessments due to the uncertainty associated with ecosystem change over long-time scales. Use of the default data (where based on empirical values) would provide a much greater data set than is likely to be available from site specific characterisation studies.

Finally, the project highlighted a potential assessment issue relating to the application of screening criteria when interpreting the results of NHB assessments. Currently there are no internationally agreed environmental benchmarks for NHB assessments, but a number of screening values have been proposed, both nationally and internationally. Such values are generally low and derived largely from effects data for mammalian species. There is therefore some concern that the use of single, low, screening values could result in NHB assessments being the limiting factor in post closure safety assessments – it was considered that screening values should be appropriate and not more conservative than approaches for humans.

Discussion

NHB screening levels are based on population limiting effects, so although calculations are done on an individual basis they are screened against population effects.

The reasons for the high level of uncertainty associated with the CR for Cl-36 in birds versus bird eggs was queried to which it was postulated that the reasons could relate to the range of empirical data for both birds and bird eggs. Should one have a greater range of values, a higher uncertainty would be expected.

Gerhard Prőhl (IAEA) explained in relation to the question over the identification of an individual for grasses and colony forming animals that the ICRP reference animal and plant approach calculates internal exposure to a single blade of grass, but for external exposure a slab approach is employed. Similar considerations are used for bees.

When assessing human impact for post closure safety assessments, a reference biosphere methodology has been developed. It was therefore suggested that it would be worthwhile trialling the reference biosphere methodology for NHB assessment. .

2.3 DEVELOPMENT OF THE BIOPROTA SPECIALISED DATABASE

Thomas Hjerpe presented.

The BIOPROTA specialised database (SDB) was originally set up as a book structure in a standalone format. Limited data are available, which were collated from primary literature sources where available. The IAEA has collated a number of data for relevant radionuclides, but these collations (i.e.

TRS documents) do not consider the links between radionuclides. The aim of the SDB is to consider such interactions as well as providing radionuclide-specific data.

Since the initial SDB was produced there has been progress toward provision of a web-access version. A portal is available, but the original SDB data have not yet been entered due to funding limitations. Nonetheless, the interactive web structure has been demonstrated and documentation has been provided outlining the key features and how they are managed. This initial phase was funded by Andra, NDA (RWMD), Posiva and SKB. Further progress has been on hold until further funding is made available and decisions made as to end user requirements.

The current version has four levels of user access ranging from read only, through data provision and scientific committee (whereby the structure and definitions can be amended), to quality control (allowing experts to check and approve entered data). A folder structure can be used for parameter organisation. End users would determine how these folders should be structured. A key benefit of the SDB is that all data are traceable from the point of their initial entry. Individual data entry is not very flexible; however auxiliary software is available which improves data entry ability.

The current SDB can be accessed from www.bsadb.net. Around 200 data entries have been incorporated. Users can access the four user levels through test accounts that have been provided. Access and passwords are as follows:

- Testlevel1 (read only), password: testlevel1@bioprota
- Testlevel2 (data entry), password: testlevel2@bioprota
- Testlevel3 (scientific committee), password: testlavel3@bioprota
- Testlevel4 (quality control), password: testlevel4@bioprota

A number of factors need to be considered in taking the web-SDB further:

- Security and back-up systems must be finalised;
- A committee for the scientific management will be required to ensure that parameter naming is not duplicated and to assist in data compilation;
- Data quality procedures will be required;
- A running contract will be required for the technical maintenance of the SDB in a longer time perspective; and,
- Consideration should be given as to requirements for off-line interfaces between the SDB and databases managed independently by sponsoring organisations.

The expectations for the web-SDB are not yet clear. The SDB could be used as a storage area for recommended values from forum members or could be a literature store (e.g. TecDoc data). Alternatively, member-specific areas could be generated whereby each sponsor would have their own folder and could set read and use rights.

If end users prefer a literature data source, the effort would be on the forum to collate and manage the SDB. If member specific areas are required then the majority of the effort would fall to each individual organisation. BIOPROTA would be required to undertake a small amount of development work related to this latter option however. A database manager would be required in all cases to ensure

documentation is up to date and to coordinate development. An administrator would also be required to undertake small uptakes and bug fixes. This is estimated to be around 2 weeks of effort per year.

Costs are difficult to determine for each of the options since exact expectations are unknown. However, if scientific management of member-specific and general areas is required, the ball-park estimate is between €5,000 and €20,000 per year. Where individual members have areas that require development, it is envisaged that individual contracts would be entered into, which would be dependant upon the extent of the development required.

For a large-scale development of the SDB, an expert group would be required to select and review data, format for input and undertake full quality assurance.

In order to fully understand the requirements of end users, it was agreed that Thomas would formulate a questionnaire to elicit views on organisational requirements and expectations. This will be used to develop a consensus view on the future of the database.

Discussion

A number of radionuclide-specific projects are currently underway within BIOPROTA (e.g. selenium, carbon, radium etc) and these may provide an economical basis for collating relevant data for incorporation into the SDB.

The benefit of having a database focused on parameters for key radionuclides associated with radioactive waste post closure safety assessments was acknowledged. This is particularly the case in the USA, which is now moving from site-specific to site-generic considerations. Such a database could be valuable in supporting a generic assessment methodology.

Gerhard Prőhl noted that the database generated by EMRAS for the revision of TRS364 is freely available and can be accessed from the IAEA website. It was considered that there may be benefit in generating a version of the database specific to geological disposal. However, in doing so there would be a need to identify those issues for which concentrated effort would be required. This could be a role for the EMRAS II Waste Working Group (identification of the most critical parameters and processes for which focus is required). However, it would be essential to ensure that the scope remained general enough to be applicable to multiple sites. The provision of such data would be a valuable tool in supporting decisions on which features, events and processes (FEPs) should be included in an assessment.

Sponsors of the forum are requested to consider their requirements in relation to further development of the SDB.

2.4 ASSESSMENT OF SE-79 IN THE BIOSPHERE

Steve Sheppard presented.

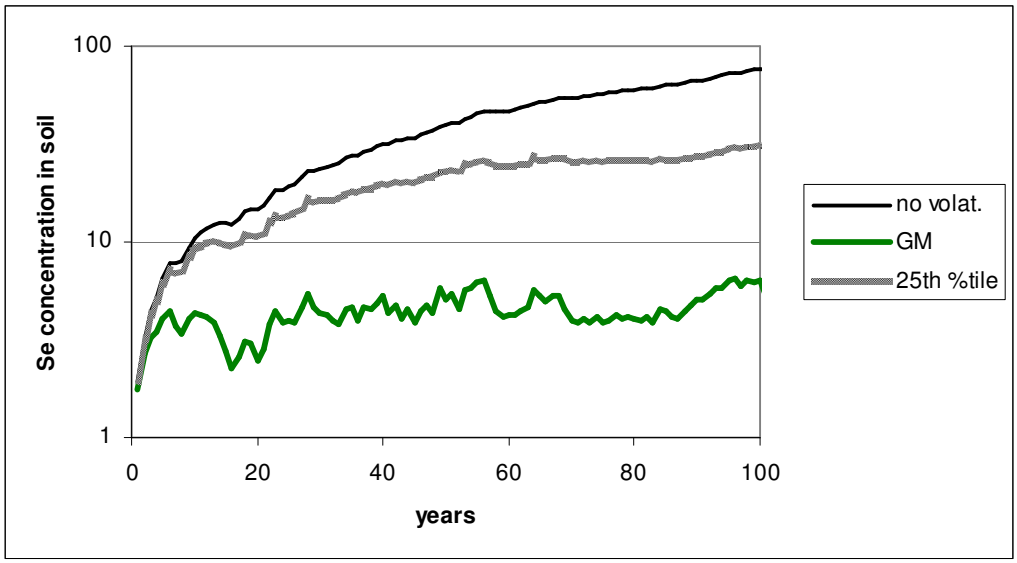
The BIOPROTA 2008 annual forum highlighted that Se-79 was one of the key radionuclides for post closure safety assessments for a number of organisations (e.g. Andra, SKB and Nagra).

There are a number of issues relating to Se-79. Selenium is an essential element, but can be toxic and can accumulate in the biosphere. In regions with a selenium deficit in soils (e.g. Finland), selenium is added to soils to ensure availability for livestock. Selenium has interesting redox behaviour, which affects its mobility and uptake into plants and volatilisation from soils. Due to its analogous behaviour to sulphur, selenium can be incorporated into amino-acids. There has also been debate in relation to the half-life of Se-79 (although this is not a biosphere-specific issue).

A project was initiated in 2008, led by Nagra on the behaviour of selenium in soils and uptake into plants in order to address some of the key uncertainties related to the behaviour of Se-79 in the biosphere. Two workshops have been held, one in Paris in March 2009, to which a number of selenium experts were invited, and a second in Madrid in May 2009 at which a list of relevant FEPs and an interaction matrix were developed. The project report outlined the following key conclusions:

- Soil pH and redox effects are key and should be included in models (these may also be important considerations for other radionuclides of interest);
- The vertical migration of selenium is a continuing issue;
- Speciation of selenium under different environmental conditions requires further consideration in models and both natural and anthropogenic (i.e. Se-79) selenium must be considered together to take account of isotopic exchange; and,
- Volatilisation of selenium may represent a large loss mechanism thus reducing the importance of Se-79 in performance assessments (volatilisation has not been considered to date in biosphere models for this radionuclide).

A number of research papers were made available to the project working group, many of which have been funded by French organisations (e.g. IRSN). For example, Darcheville et al [2008][a] looked at selenium speciation and concluded that up to 0.5% of selenium in soils is volatilised per year. Février et al [2007][b] demonstrated that microbial activity has an influence on the distribution coefficient (Kd) of selenium in soils. Volatilisation half-time for selenium does not appear to be directly related to the majority of soil properties, but a slight relationship is observed in relation to soil carbon content. When volatilisation is taken into account in biosphere models, much lower concentrations are estimated:



[a] Darcheville et al. 2008. Aqueous, solid and gaseous partitioning of selenium in a sandy soil under different microbiological states. JER 99, 981-992.

[b] Février et al. 2007, Variation of the distribution coefficient Kd of selenium in soils under various microbial states. JER 97, 189-205.

2.5 CL-36 PHASE 2: DOSE ASSESSMENT UNCERTAINTIES AND VARIABILITY

Laura Limer presented.

Phase II of the Cl-36 project involved 9 participant organisations, including:

- Andra, EdF, IRSN, Societé de Calcul Mathématique (France);
- JGC Corporation, NUMO (Japan);
- NDA RWMD (UK); and
- EPRI, Oregon State University (USA).

IRSN and JGC Corporation provided supporting technical information rather than participating in the modelling exercise. David Bytwerk (Oregon State University) was specifically acknowledged for having undertaking much of the project work.

Chlorine-36 is one of dominant radionuclides for post closure safety assessments, particularly in relation to graphite waste forms; however there are notable uncertainties associated with dose assessment parameters, particularly in relation to accumulation in soils and uptake into plants. The aim of the project was therefore to look at the scientific basis for the different assessment approaches used. Phase I focused on plant uptake from soil. Phase II further developed the scope to take account of Cl-36 uptake to animals and human doses.

A range of models are applied in relation to Cl-36 post closure safety assessment modelling, which have different conceptual basis, including:

- Conventional models, which incorporate a Cl-36 residence time and accumulation in root-zone soil; an instantaneous equilibrium soil-water coefficient (Kd) to determine the available fraction for uptake by plant roots; a fixed soil:plant concentration ratio; and a transfer factor approach for uptake into animals. Examples include IMARC, ERB2A and Aquabios.
- Specific activity models, which assume that Cl-36 in soils and plants is in equilibrium with stable chlorine and that this ratio remains constant. A similar approach is used for uptake into animals whereby the ratio of Cl-36 to stable chlorine in an animal is equal to that in the plants consumed. Some consideration is given to stable chlorine dietary requirements for both agricultural animals (which may be given supplementary feed to maintain optimal meat production) and humans. Examples include AquaCl36 and SA_36Cl.
- In more complex models, plant uptake is both passive and active. Models include organic chlorine, which takes a longer time to accumulate in soil when compared with inorganic forms; however, for soils with a slow turnover, build up could occur over timescales of thousands of years and the organic pool could be larger than the chloride pool. Uptake to animals employs a concentration factor approach, but stable chlorine requirements of animals are taken into account. The complex model included in the current project was MTA_Cl36.

The scenario assumed fixed Cl-36 and stable chlorine activity concentrations in groundwater and stable chlorine concentration in rain water. Climate data were provided for a site in France. Irrigation volume and timing was site dependent. Four crops root vegetables, leafy green vegetables, cereal and fruit), five animal products (beef, milk, milk products, chicken and eggs) were considered. Modern agricultural methods (including fertiliser application) were represented. Some foliar uptake following

irrigation water interception was assumed. Doses were calculated for three human exposure groups (adults, children and infants).

In analysing results, all reasons for model result variation were considered, including differences in the models themselves, the exposure groups considered, consumption rates, contamination of animal fodder (irrigation of pasture that animals graze upon was assumed in this case) and degree of autarky (whether or not all food consumed by humans could be grown within the potentially contaminated zone). Results indicated that soil concentrations equilibrate after 10 years; hence 10 year data were used for dose calculations.

Results indicated that the Aquacl36 model was the most conservative with soil concentrations an order of magnitude greater that in the other models employed. This model includes the addition of stable chlorine as a result of marine influences (specific activity or more complex approaches are required to take account of this stable chlorine influx).

Results for Cl-36 in plants showed that conventional models gave higher predictions. Not all models considered foliar interception. Fruits were generally calculated to have the highest Cl-36 concentrations, which may result from the use of iodine/caesium analogues for foliar uptake and translocation; work ongoing at Andra and IRSN may provide chlorine specific data for these pathways. The need to take account of the chlorine flux through all transport processes was highlighted – there is a need to ensure that foliar uptake of stable chlorine from irrigation water is appropriately compensated by other processes such as root exudation.

Root uptake data was based on information in the scientific literature, but there is an issue as to which plant tissue should be selected in representing root uptake (e.g. grain or stem). The complex model incorporated active uptake and passive uptake, calculated on the basis of an estimated transpiration stream. Both root uptake and exudation are considered, by including the process of diffusion. However, it was noted that this approach has not yet been validated against experimental / field data. Relevant data may be produced by the PhD studies being undertaken by David Bytwerk on plant uptake of Cl-36. Projects are also ongoing at IRSN on the translocation of radionuclides following irrigation. It is anticipated that further BIOPROTA work on Cl-36 could be undertaken once such data are available.

Differences in Cl-36 model predictions for animals in part arose in relation to irrigation assumptions for cereals with some models assuming that irrigation led to the contamination of the crop prior to feeding to cattle whereas other models assumed that cereals for human consumption are irrigated, but those for cattle consumption are not. In such instances, drinking water is the only source of Cl-36 intake for cattle. Stable chlorine data from IRSN has indicated that concentrations in cheese could be up to 10 times greater than in milk. Models which employ a specific activity approach used similar ratios whereas concentration factors were used in other models to take account of this enrichment. This difference in approach led to differences in results, largely since the addition of salt to cheese affects stable chlorine concentrations, which would not occur for Cl-36. The effect of the use of salt in food preparation on Cl-36 predictions may therefore need to be addressed.

Human dose predictions were within a factor of 8. A general increase in dose was observed from adult to infant, which is partly due to diet assumptions (infants consume more milk and milk products than adults), but also to the dose conversion factors used.

ICRP dose coefficients were used in the assessment, which are derived on the basis of particular assumptions on diet and stable chlorine concentrations; they would be affected by varying assumptions on the amount of stable chlorine consumed. Dose coefficients were therefore considered

that took account of the total stable chlorine ingested in diets using a scenario-specific consensus diet. This indicated that higher dose coefficients would be obtained for adults and lower for children and infants than those recommended by the ICRP:

	Daily chloride intake (g d^{-1})		Dose Coefficient (Sv Bq^{-1})		
	ICRP Assumption	Consensus diet	ICRP (1996)	Consensus diet (calculated)	Ratio
Adult	5.2	2.5	9.3E-10	2.0E-09	2.2:1
Children	2.6	3.3	1.9E-09	1.6E-09	0.8:1
Infants	0.74	1.4	6.3E-09	3.7E-09	0.6:1

This leads to an increase in adult doses when new dose coefficients are applied and serves to level out dose results between the different age groups.

The project concluded that no particular source of variation could be assigned to particular model approaches. Conventional models require stable chlorine data and site characterisation work would help in selecting appropriate parameters.

Remaining issues include:

- Foliar uptake mechanisms, which could be addressed through laboratory and/or field experiments; and,
- Speciation of chlorine in milk and milk products (and whether this results from the addition of salt and/or other factors).

Reports from both Phase I and Phase II have been published from by Andra and are available on the BIOPROTA website. A peer-reviewed publication on the work is currently being progressed.

Discussion

Whether or not specific activity models were appropriate for modelling chlorine in the biosphere was questioned; in general it was considered that this is an appropriate approach due to the long-term nature of the assessments being undertaken.

Chlorine is applied to the environment in many fertilisers and as a treatment to roads in winter when snow and ice are an issue. It was considered that the chlorine must be removed from the system or no plants would be found growing in the immediate vicinity of roads; thus suggesting that chlorine would not accumulate, but rather be transported to deeper soil layers. The long-term issue for chlorine was therefore questioned. However, this would be the case for chloride (as applied to roads), but organic forms may show a different behaviour. Work conducted in Sweden on the accumulation of chlorine in the environment following road salting has indicated that less chloride is leached from soils than is added; thus some retention may occur. Overall, information on the residence time of chlorine in different types of soils is lacking. Consideration must be given to the chemical form that is present. Chloride can be rapidly converted to hyperchloride, which reacts rapidly with organic matter in the presence of some enzymes. This process particularly occurs in organic soils that are dominated by micro-organisms and fungi.

2.6 OVERVIEW OF THE BIOPROTA RADIUM WORKSHOP

Graham Smith presented.

A workshop on the behaviour of radium in the biosphere was held from 4-5 May 2010, hosted by Andra. The workshop was funded by Andra, NUMO, NRPA, NDA (RWMD) and SKB. The objective was to share information on the behaviour of this radionuclide with a view to improving confidence in prospective long-term assessments of public radiation exposure arising from radioactive waste management activities. There is a lot of commonality in interests in uranium series radionuclides for long term radiological assessments – the source of the radium is not important since assessment issues are similar; we need to understand how radium migrates in the environment between different media to accurately assess internal (ingestion / inhalation) and external exposure pathways. Different communities were therefore brought together by the workshop.

The workshop was attended by 29 participants from 7 countries and 12 major organisations that were concerned with deep, near surface, mining, NORM and/or nuclear fuel cycle wastes. Different wastes are dealt with in very different ways, some are highly engineered systems; others consist of tailings piles upon which dwellings have been constructed. Concerns with radium include foodchain uptake, but also external irradiation and the emanation of radon.

The workshop focused on a number of topics, including:

- the most recent information/knowledge on radium transfer between soils and plants;
- the weathering and leaching processes controlling radium solubility in soils and sediments;
- the possible evolution of radium distribution between the host rock and the product soil or within the soil profile over long time scales;
- the microbial mechanisms important for radium liberation or co-precipitation; and,
- the application of the most appropriate model to categorise soils in terms of radium mobility.

A number of presentations were made, many of which served to identify where data on radium exists or might be found:

- Phosphogypsum amendments in agricultural soils;
- Radiological characteristics of the environment around a former uranium mine;
- Uranium and its decay products in the human food chain;
- Radium mobility and cycling in re-vegetated mining debris;
- Radium sorption on soils;
- Radium and its progeny in mammals;
- Estimation of soil to plant transfer factor of Ra-226;
- Predicting radium availability and plant uptake: Proposal for new best estimates of Kd and TF for radium;
- Radiological characteristics of the environment around a former uranium mine;
- Environmental behaviour of Ra-226 in aquatic and terrestrial ecosystems;

- Data requirements to determine effective distribution coefficients for radium in soils (based on reactive chemistry);
- Ra-226 in the biosphere in a Swedish safety assessment; and,
- Treatment of radium in the Andra biosphere impact assessment.

A number of assessment weaknesses were identified. For example, it was considered that current approaches have an overly simplistic representation of the accumulation of radium in soils, given the importance of radium and its daughters in many assessment contexts. Assumptions need to be justified within models (including justification for the exclusion of any FEPs that may be relevant to radium); thus it was considered that more complex consideration of soil accumulation is required in the first instance. At present the knowledge base is more complex than the modelling approaches employed. Should results of more complex approaches be similar to the simpler approaches, this would provide justification for the simpler approaches used.

Some contradictions were noted during presentations on radium behaviour, particularly with regard to whether correlations are present between the presence of radium and soil parameters and issues were identified with the large range of values reported for concentration ratios and Kd. This is not helped by the lack of references for which enough supporting information on the soil conditions and/or experimental system is provided to support model development. Such information is important in identifying when particular parameter values should, or should not, be applied.

Data gaps and uncertainties identified included:

- Lack of thermodynamic data, which is required in order to determine radium behaviour in relation to organic matter;
- Data on the accumulation of radium in sediments;
- Information on the effects of environmental change, which may result in the remobilisation of radium that has accumulated in soils or sediments and which could give rise to rapid changes in bioavailability; and,
- Information on the transfer of radium to crops and animals.

All of the above have the potential to affect our predictions on the distribution of the daughter products of radium, i.e. Pb-210 and Po-210 which may dominate the radiological impacts and this may lead to further assessment uncertainties.

A number of ideas for resolution of the remaining gaps and uncertainties were discussed:

- Original data sources could be further analysed in order to resolve issues regarding different interpretations of the data (data could also be provided, as a result of such a process, as input to the BIOPROTA SDB). It would also be beneficial to try and obtain more of the original source data in order to more fully understand what are the important factors governing radium environmental behaviour (for example, what are the key factors affecting Kd). Further information on radium complexation may be required.
- Relationships between concentrations in the environment and those in foods and people could be reviewed. Measurements could be made for comparison against model results in order to identify the level of accuracy of different models and to determine the degree of

conservativeness in the approaches applied. Historic uranium mine sites may provide relevant data from monitoring programmes that have been undertaken.

Overall, much positive feedback was received in relation to the workshop; not least that it provided a key opportunity for different communities to come together and to collaborate on a subject that is of joint interest and for which the sharing of information is of great benefit. A report of the workshop has been completed and distributed to participants and project sponsors, and is expected to be made available at www.bioprota.com in due course.

3. CHALLENGES IN RADIOACTIVE WASTE MANAGEMENT AND BIOSPHERE ASSESSMENTS

The following sub-sections give an overview of the presentations provided by the various participants on their radioactive waste management and biosphere assessment programmes.

3.1 BIOGEOCHEMICAL ZONATION IN QUATERNARY DEPOSITS (QD) AND SOILS - FIRST IMPRESSIONS FROM SSM'S REVIEW

Ryk Klos and George Shaw presented.

SSM is undertaking a review of the SKB descriptive model assessments. A part of this review involves the development of models that allow SKB concepts to be individually assessed and to ensure a full understanding of the processes considered. A key objective is to determine how models relate to the Swedish radiation protection objectives, ensuring that geosphere releases are linked to regulatory risk limits. By undertaking independent model development on the basis of the site characterisation work conducted by SKB, it may be possible to identify whether any relevant FEPs have been excluded.

Sweden (and other Scandinavian countries) are subject to post-glacial land rise. This has resulted in a small quaternary deposit (QD) layer (typical thickness a few metres, though usually thinker in agricultural areas,). Over time, land rise will result in the migration of the coastline with terrestrial ecosystems evolving from lake and marine systems. Since the main interest for post-closure assessments is dose to humans, agricultural land is a key concern since wetland areas are not productive enough to be able to support populations. Consideration has to be given to the conditions prior to the development of agricultural land as this will influence the accumulation of radionuclides. An integrated landscape model has therefore been developed, which is based on the topography of the land and seabed. The landscape model incorporates lake, wetland, forest, agricultural and stream components. There is an overall progression from lake sediments to wetland soils. These can then be drained leading to a step change to agricultural land.

Fracture releases are considered and the dispersion of radionuclides from these fracture zones assessed. A period of time is required for the migration of radionuclides, released from fracture zones, through the soil profile.

Aggregated transfer factors are applied in the calculation of doses. Carbon availability restricts the number of people that can survive on an area of 10^{-4} ha to around 10 adults. If an area of land must be larger to support a population then an autarky fraction is applied.

The accumulation of radionuclides in the lower QD under different conditions has been investigated. Saturation of QD affects the flow of radionuclides. The main water fluxes come from precipitation and these move primarily in the upper layers in the variably saturated zone. The deeper layers are larger immobile and there is little input to the base of the QD from the bedrock. Radionuclide accumulation in the deeper QD is possible and the location of the saturated layer and movements of the water table are important to the upward migration of contaminants.

A further part of the work being undertaken is to explore some of the real mechanisms in the environment that provide the potential for radionuclide accumulation in different parts of the biosphere. Where radionuclides accumulate in the biosphere can have a large effect on dose. The focus has been on chemical zonation and redox using example radionuclides (iodine, selenium and technetium), all of which are redox sensitive and accumulate in different parts of the soil:plant system.

In looking at a sub-surface input of radioactivity, biological pumping and recycling effects are often omitted, but can be important in different circumstances.

The the region between the unsaturated surface and the saturated soil column migrates vertically and is seasonally affected. The chemical and biological characteristics of the upper and lower soil zones differs. The unsaturated zone is characterised by a higher organic matter content, greater redox potential (iron and manganese occur in the oxidised form) and certain radionuclides (e.g. selenium and technetium) can be highly mobile whereas others (e.g. iodine is present as iodate) are relatively immobile. The converse is true with lower soils thus there is inversion of radionuclide behaviour (iodine is present as iodide which is highly mobile whereas selenium and technetium form relatively immobile species). These radionuclides would therefore be expected to accumulate in different regions.

Vertical profiles from flux experiments (with basal input) showed a redox boundary which affected Kd. Iodine was found to accumulate at this redox boundary.

Stable element profiles for iodine selenium and rhenium indicate that these elements have a strong relationship with organic matter content and this strongly influences the position in the soil profile at which they accumulate. Many Kd values are derived from tracer experiments rather than stable element data and, as such, tend to be short-lived. Limitations in application are therefore noted. It was noted that Steve Sheppard has compared stable element and tracer Kd results and differences were observed. There is therefore a need to consider which data are more appropriate for long-term modelling.

New Kd data are becoming available (largely as a result of the EMRAS programme) and supportive information is required (e.g. soil type, organic matter content) to assist in parameter selection. It should also be borne in mind that upward vertical transport will differ with seasonal conditions and the effects of this have been investigated.

Water flux balances for lysimeter experiments conducted in southern England have investigated evapotranspiration and precipitation over 4 years. In warm dry summers, Cl-36 was observed to migrate upward from the water table and accumulate in the upper soil profile. In average summers, vertical migration was reduced. Vertical migration studies conducted by SKB have also shown a net upward movement of water and solutes in summer. Deep rooted plants have been shown to access the water table directly.

Information on water and solute transport has been captured in a simple model which considers three soil layers (unsaturated top soil, variably saturated sub-soil and saturated deep soil). The degree of saturation determines the redox conditions; thus Kd is varied according to soil layer. Uptake of radionuclides by vegetation from each soil layer is dependent upon a root distribution function, which reduces with depth. Groundwater concentrations are kept constant as was the water table position. Vertical transport of radionuclides was investigated both with and without the influence of root uptake.

For iodine, both upward and downward fluxes are observed in the absence of root uptake. However, when root uptake is included, there is a large transfer into the above soil compartment. For technetium there is a greater accumulation in lower soil zones thus root uptake has a lower influence although some transfer to the above soil compartment is observed due to deep roots. Radionuclide transport is therefore impacted by considerations of Kd and root uptake in relation to soil layers.

Discussion

In arid climates, capillary action (without the influence of vegetation) is strong and leads to upwelling of groundwater and formation of solid precipitates on the soil surface.

For lysimeter experiments it was explained that the relationship between iodine in soil columns and iron and manganese concentrations has not been analysed, however full redox measurements have been undertaken.

3.2 CURRENT STATUS OF THE SKB PROGRAMME

Tobias Lindborg presented.

SKB is a privately owned company that is responsible for the disposal of spent nuclear fuel from power plants and other nuclear waste. A central interim store for spent fuel and higher activity wastes waste is located 300 km south of Stockholm and a LLW repository is already operational at the Forsmark site, which was selected as the Swedish site for a spent fuel repository in 2009. The SKB programme is currently focused on the safety assessment for the spent fuel repository. Work is still in progress so results from the assessment are not yet available. The final application for construction of the repository is due to be submitted by the end of 2010. The application will detail the reasons for the selection of Forsmark as the final disposal site. If the application is successful, disposal operations are due to begin in 2023.

The disposal concept is based on the KBS-3V design whereby copper canisters are placed in holes in the bedrock at 450 m depth and surrounded by bentonite clay.

A detailed site investigation programme has been undertaken over the last 6/7 years, which largely focused on the properties of the bedrock and its performance characteristics. The function of the biosphere was also investigated.

The current biosphere assessment programme (SR-Site Biosphere) is a sub-programme to SR Site, and has 22 people working on it. Sixteen of these were directly involved in the previous site investigation programme so have a detailed understanding of the site and available data. The project started in 2009 and will complete in January 2011. The output will be 15 or more reports supporting the safety assessment. Different levels of reports are intended to feed into one another and a large amount of work is required to ensure they are linked correctly. All are currently under production.

For Forsmark, one reference glacial cycle is assumed (the Weichselian), which repeats every 100 000 years over a 1 million year assessment period. This cycle is used as an analogue for future cycles. The cycle predicts peri-glacial permafrost conditions at different times. When large-scale ice cover is predicted, this leads to bedrock submergence and shoreline displacement.

In order to gain understanding of processes in specific systems (e.g. lakes) in the future, analogues have been used. For example, Greenland lakes are used as analogues for permafrost lake conditions. Transport windows between permafrost conditions allow radionuclide migration.

Landscape development is a key consideration for the Forsmark site and a landscape development model has been developed, which is in turn fed by models for hydrology, sedimentation etc. The locations of rivers and lakes are based on information on land topography which informs likely water flow paths. The sedimentation model shows how the QD and regolith develop and also indicates vegetation succession. Examples from the present landscape, such as newly formed lakes, provide clear examples of what could occur in the future. Additional models are used to predict where discharges are likely to occur and form the basis for dose calculations. The intention is not to try to predict the future but rather to show relevant examples of how the site could evolve over time.

Landscape and hydrological information are used to identify biosphere objects that could be affected by repository discharge. Physical boundaries (based on topography) identify lake drainage areas and biosphere flow directions. Mass balance is used to estimate flows.

A single radionuclide model has been developed for all future ecosystem types, which considers both terrestrial and aquatic environments. Landscape dose factors are calculated as a function of time, taking account of the size of human population that can be sustained by a landscape object and the location of the discharge area to give a deterministic dose prediction. The highest dose conversion factor has been calculated for Cl-36. Discharges are predicted to occur in agricultural areas in around 4,000 years time to an area that can sustain 80 people (based on a self sustaining society). It is assumed that individuals receive a dose over a 50 year period during which time they remain within the area. Ra-226 has been assessed to be one of the main contributors to dose for the scenario of early canister failure.

Probabilistic dose calculations can be performed to determine the distribution of results compared with deterministic predictions.

Discussion

Radium-226 is important to dose due to in-growth from U-238 that has been released from the repository and migrated to the surface environment. Conservative predictions estimate that radium concentrations from the repository will be at most double natural background (from all radionuclides) in the case of pessimistic assumptions for near-field and geosphere containment.

3.3 PHENOMENOLOGICAL AND MONITORING STUDIES IN THE CURRENT 'BIOSPHERE' PROGRAMME AT ANDRA

Yves Thiry presented.

ANDRA is currently focused on phenomenological aspects of the HAVL programme. The key objectives for 2010-2014 are to focus on:

- The fate of the key radionuclides Se-79 and Cl-36. Iodine-129 is also important; however it is considered that adequate information is already available; aquatic pathways are the most important for this radionuclide.
- Reduce uncertainty in parameterisation (e.g. Kd, translocation) by more realistic site-specific modelling and data selection.
- Developing the approach for dealing with existing and future ecosystems (cultivated land, pasture and forest) in colder and warmer climates than present today.

Current activities include:

- The effect of climate on soil type, which helps to improve predictions for future ecosystems;
- In situ studies on the transfer of key radionuclides for which results are likely to be available in 2011;
- Selenium speciation and mobility, which is being researched as a PhD project;
- A new collaborative action is anticipated between Andra and EdF on mineralisation processes.

When analogues are being using to estimate soil changes in the long-term in cold climates, similarities between current and future soils are expected. The HAVL disposal site is comprised of clay alkaline soils that are relatively dry. These are unlikely to change to a large extent over time. Slow rates of decarbonation and chemical weathering are likely to occur. However, if climate conditions change, this could affect organic matter content and redox conditions. Greater rates of decarbonation would be expected in warmer climates. Alkaline clay soils would still be anticipated however due to the buffering capacity of such soils.

- A further programme is looking at foliar translocation of chlorine, iodine and selenium in four model plants from both chronic and pulse contamination (simulating irrigation). This programme is being run under field conditions.

  The first study was completed in 2009 with exposure of plants occurring at different development stages. Very low translocation factors were observed for iodine (maximum value of 2%). Development stage of the plants did not result in differences in the translocation factors observed.

  Translocation was more important for selenium, particularly in potato tubers and radishes. Higher values still were observed for chlorine. Young plants showed greater translocation, which was due to the greater chlorine requirements of young plants. A second round of experiments is to be undertaken to confirm these results.

- A PhD is underway on the relationship between selenium speciation, mobility and bioavailability. The work aims to develop a method that will allow speciation to be monitored and must ensure that the chemical form of selenium is preserved when sampling soils. The influence of soil properties will be investigated on the basis of the range of organic matter content and the impact of vegetation on the organic matter gradient will be considered.

  Various selenium extraction agents have been tested. Extraction by water was low, but sodium hydroxide extraction was high suggesting a link between selenium and organic matter. Soils are dominated by the selenite form. Selenate is only present in the water fraction. These results have been confirmed through extractions from agricultural, pasture and forest soils. Water extraction was low for all soils (5-8%) whereas sodium hydroxide extraction was more variable for different soil types. The highest mobility was observed for agricultural soils. Organic matter served to reduce bioavailability, but the principal form of organic matter involved is currently unknown. Up to 30% of selenium is hypothesised to be in colloidal form.

- A further study is investigating the variability of organic and inorganic chlorine pools in terrestrial environments. Chlorine deposits and their relationship to soil type are being investigated with the aim of being able to predict relationships between chlorine contents and soil type and climate across France; thus a range of soil types and conditions are being considered. Chlorine concentrations in litter fall and humus as function of a decay coefficient, which reflects turnover of organic matter, has been ranked. A high variability of chlorination rate with organic matter turnover has been observed, but a slight trend is evident. This trend has been used to obtain an upper long-term chlorination rate of 0.1 $g/m^2/y$.

- The Planning Act of 2006 resulted in an observatory programme at Andra and a monitoring system has been launched. The objective is to have an observatory for a period of 100 years (to be consistent with the time scale of the installation) and to ensure that the initial state of the site has been characterised prior to construction (enabling the origin of any environmental

disturbance to be explained). A multidisciplinary approach is being employed to ensure traceability in data and to preserve samples taken.

The observation zone is large and will be adapted around Andra facilities. The area is rural and is characterised by mixed ecosystems.

Current initiatives in the observatory programme are to obtain an inventory of flora and fauna and agricultural production, and to monitor forestry and agricultural practices. The radiological and geochemical background will also be established. All data obtained will be compiled in a database complete with a GIS system and will be integrated into national and international data networks. Experimental plots will also be established to investigate ecological functions.

Samples will be stored in a specimen bank until at least 2017 to ensure that repeat analysis is possible for verification purposes.

3.4 CURRENT SITUATION OF BIOSPHERE MODELLING APPROACH IN SPAIN

Danyl Perez-Sanchez presented.

CIEMAT is a research organisation that supports ENRESA – the Spanish waste management organisation. Spain currently has eight operation nuclear power plants plus a fuel processing plant. Closed uranium mines are also present. The Spanish nuclear cycle and energy context is based on a nuclear power plant lifetime of 40years. Based on current capacity, the following quantities of low and intermediate level waste (LILW) and high level waste (HLW) are anticipated:

Waste Type	Source	Quantity (m^3)
LILW	Fuel Fabrication	520
	NPP Operation	36620
	Small Producers	6280
	NPP dismantling	137640
	Other installations dismantling	1060
	Other sources	5230
Spent Fuel	NPP	10000
HLW	NPP	80

2010 is an important year in Spain for HLW since vitrified fuel is being returned from France. A means of storing or disposing of this fuel is therefore required. A flexible research and development plan has been developed by ENRESA, which is focused around:

- Providing support for a Centralised Temporary Storage (CTS) facility and ENRESA operating installations, including those that are to be dismantled;
- Developing separation and transmutation capacities; and,
- Providing support for basic generic long-term storage projects.

This last objective is currently on hold until a temporary store for vitrified waste returned from France is completed. A distinction is made between interim and final disposal solutions in recognising the

need for further analysis of long-term options. The overall objective is not to develop new technology, but rather to improve upon current technology.

The current disposal facility for LILW (El Cabril) is envisaged to have sufficient capacity until 2020. Research and development activities for this waste facility are focused on the performance of containment barriers.

Discussions on the location for disposal of HLW and spent fuel in Spain are ongoing and it is anticipated that a solution will be available by the end of 2010. No formal long-term management decisions are likely for around 12 to 20 years, during which time efforts will focus on improving radiological protection through new restoration and decontamination technologies.

CIEMAT is currently looking at international biosphere assessments as a means of improving the national approach to modelling radionuclide transport in the biosphere. The intention is to maintain capability in biosphere assessments, by both improving general capability and understanding and also by applying generic methods to other problems in Spain such as NORM. The overall aim is to develop conceptual models for key radionuclides in the biosphere, that are applicable to the Spanish situation (Spain has varied geography, climate and meteorological conditions throughout the country).

Uranium-series modelling is a particular focus due to the importance of the NORM industry in Spain. ENRESA aims to ensure capability in biosphere assessments for NORM in case regulations change, thus changing the Spanish approach to NORM disposal.

3.5 YUCCA MOUNTAIN PROJECT UPDATE

Maryla Wasiolek presented.

Fuel and other waste that was destined for the planned Yucca Mountain repository includes commercial spent fuel, US Department of Energy (DoE) and defence related spent fuel (e.g. naval fuel from submarines) and vitrified waste from nuclear weapons. Of these sources, commercial fuel is the major component.

Fuel is currently located at 121 sites in 39 states, the majority of which are co-located with nuclear power plants in the east of the USA. The planned repository would have been at Yucca Mountain in Nevada in the west; thus transport of radioactive waste would have been required over large distances. This was one of the arguments for the Yucca Mountain project no longer going forward.

Currently there is around 60,000 metric tonnes of heavy metal (MTHM) that would be destined for a repository. However, if license renewals for existing plants are granted, this may increase to between 110,000 and 130,000 metric tonnes. This could be further increased with the construction and operation of new reactors for which several applications are currently under review. In addition to the spent fuel stored at operational reactor sites there are 13 cask storage facilities in 9 states resulting from closed reactors. Disposal of theses wastes is a priority. The US DoE is obligated under US law to take ownership of the spent fuel from commercial reactors and already owns all defence related wastes.

One solution was to open the Yucca Mountain repository. The procedure was that the US DoE had to apply to the Nuclear Regulatory Commission (NRC) for a license to construct a repository which, if successful, would have been followed by an application to operate the facility.

The application was successfully reviewed against regulatory requirements and the application was docketed, which led to the processes of technical review and consideration of legal challenges. These processes are proceeding in parallel.

Technical review of the application is being done by the NRC and this, by law, must be completed within 18 months of docketing; however, financial constraints mean that it is unlikely that this deadline will be met. The review was mostly on track until February 2010. A variety of requests for further information have been submitted to the US DoE by NRC, which include technical issues relating to disequilibria between radionuclides; as model assumptions were perceived to be conservative, but led to non-conservative assumptions for decay products. All interactions occur in a public setting to ensure transparency. The information provided will support the development of a safety evaluation report. It has been indicated that two volumes out of a five volume report will be completed by November 2010, one of which will document the findings with respect to the post-closure safety assessment. The remaining volumes are unlikely to be available until 2012.

Legal challenges to the repository are heard before the Atomic Safety and Licensing Board. The hearing process allows members of the public and organisations to have opportunities to express discontent and raise concerns with respect to the license application. Over 300 contentions have been submitted, the majority of which have been permitted by the Atomic Safety and Licensing Board. Only three of the contentions related to the biosphere. Once contentions have been filed, the US DoE has the opportunity to respond and a further response from those raising the contentions is then permitted.

A formal discovery step should have begun in the spring in which the various parties would have conducted deposition hearings addressing both legal and technical issues through an initial examination of witnesses. It is a legal requirement that the NRC make a decision on the construction authorisation within three to four years following application. However, in February the President of the United States published a proposed budget for the next fiscal year – no money was allocated for Yucca Mountain. This budget is to be decided upon by Congress.

On the same day as the proposed budget was submitted, the US DoE informed the NRC of the intention to withdraw the Yucca Mountain license application and requested that proceedings be suspended in relation to the granting of a licence to construct. The request was granted by the NRC in February and, as a result, the legal process has been suspended; however, the technical review is ongoing. A formal request to withdraw the application with prejudice was made in March, which means that an entirely new application would be required to restart the process. This resulted in a number of new entities petitioning to participate in the legal process. These are entities with interests in the Yucca Mountain repository proceeding as planned such as those with nuclear fuel to be disposed of and those representing rate payers ($17 billion has been contributed by rate payers to the repository fund). The new issues are focused on whether the US DoE had a legal right to withdraw the application.

Independent of the NRC and legal challenges, there are at least six cases challenging the withdrawal of the licence application by the DoE before the US federal court of appeals. These are challenging the authority of the US DoE in withdrawing the application since the process stems from the Nuclear Waste Policy Act. The Nuclear Energy Institute has also filed a law suit to refund rate payers contributions to the nuclear waste fund. These court cases are pending.

In May, the US DoE gave formal technical direction to contractors (e.g. the Sandia National Laboratory and US Repository Services which are responsible for the post-closure assessment contract and pre-closure safety assessment, respectively) to cease all activities.

The future of nuclear waste may be decided by a Commission that was established in December 2009, which consists of around 12 experts. These experts are expected to rule on the future of nuclear fuel and HLW. Yucca Mountain is not an option being considered.

Discussion

Based on projections for waste fuel volumes, there would not have been enough space within Yucca Mountain. Two repositories would have been required. This is due to an artificial cap being placed on the size of the Yucca Mountain repository to ensure that a second facility would be required. There would have been a legal requirement for this to be situated in the east of the country. However, once construction of the first facility began, this cap would have been lifted, enabling a larger construction to occur such that Yucca Mountain could take all waste.

There is a need to ensure that lessons learned from the Yucca Mountain project are not lost and this will require careful archiving of the information generated. It is possible that the US DoE will be responsible for archiving this information with funds made available from the nuclear fuel programme. However, at present, the federal government is responsible for archiving since the legal process is still ongoing due to the current legal challenges.

3.6 BIOSPHERE ASSESSMENT BSA-2009 FOR THE OLKILUOTO SPENT FUEL REPOSITORY: OUTCOME AND NEEDS FOR FURTHER WORK

Ari Ikonen and Thomas Hjerpe presented.

The biosphere assessment for a spent fuel repository in Finland has a similar history to that for SKB. Feasibility studies began in 1978 and a site was selected in 1999. A decision in principle was granted by the government in 2001. Since that time, work has focused on confirming the suitability of the selected site through a detailed site characterisation programme. A construction licence application is due to be submitted in 2012, which, if successful, will pave the way for disposal operations to begin in 2020.

Like SKB, disposal is based around the KBS-3V concept, but a horizontal variant is being considered.

Geological evaluation of Finland initially identified more than 100 potential sites for a spent fuel repository. From these, five were selected for preliminary site characterisation. The municipalities did not strongly object. The final selection of Olkiluoto Island in municipality of Eurajoki was in part due to the co-location with existing nuclear power plants, but was also influenced by socio-economic factors. The site is close to a larger Finnish town, Rauma.

A rock characterisation facility (ONKALO) has been under construction since 2004 and is now approaching final disposal depth (420 m). Once this depth is reached, the facility will be expanded to further investigate the bedrock prior to being expanded into the final repository if government approval is granted.

As with the Swedish situation, the Finnish disposal site is subject to post-glacial rebound; thus there is a need to determine how the biosphere will evolve over time. Consideration also has to be given to how radionuclides will be transported and accumulate throughout the biosphere of the relevant future and how the area will be utilised by both people and non-human biota. These questions are being systematically addressed through a formal biosphere assessment process, which starts with a biosphere description that integrates site data and transport and landscape evolution processes. How the terrain will look in the future is then considered. Finally dose calculations are performed. Different climatic scenarios are assumed.

The biosphere description programme is focused on analysing present conditions. The biosphere description report (Posiva report 2009-02) has been published and is available from the Posiva website. The first part of this report provides an analysis of the site data. Processes (interactions) are

then considered and related to the development of ecosystem models that are based on a mass balance approach. The third part of the report provides the site-understanding-informed model input data. Overall the report provides data that will feed into further assessments.

The repository site is characterised by many forest areas and mixed meadow and mire areas that arise as a result of land transitions. There is a large shoreline area, which is advancing with land rise. Clays tend to be the dominant form of soils due to deposition in present, underwater depressions and these may develop into future agricultural areas which, like those at present, are largely located in river valleys. Most of the soil is rather infertile till, though, so forests are expected to dominate the landscape also in the future. The nuclear power plants exert a large anthropogenic influence on the area.

Off-site lakes and mires are used as analogues for the future since they lack from the present site. A large reference area has been identified, which covers ecosystems representative of the past 8,000 to 9,000 years of land evolution. This area is being researched to gain information on the historical generation of land areas to inform as to possible future land generation.

A FEP analysis has been undertaken and transport (interaction) matrices have been developed for the overall biosphere system. The matrix expands into more detailed levels. Site data have been collected to support the identified FEPs, resulting in the production of a large database.

An uncertainty assessment is being undertaken to determine how reliable models are, which will help inform those responsible for making decisions on the repository. This is based around Knowledge Quality Assessment (KQA), which is systematically applied throughout the assessment. One tool in KQA is the data quality index whereby data are scored according to a score matrix to determine reliability and compared against the sensitivity of the assessment results to changes in related input parameters. Based on the outcome of the KQA, further research areas can be identified. For some parameters (e.g. Kd and concentration ratio), not many site-specific data are available. It may therefore be a requirement for site data to be supplemented with literature-derived data to ensure an adequate consideration of variability.

The main challenge for Posiva at present is to ensure the quality and applicability of model input data in its safety assessment – if inappropriate data are used as input then the results will not be reliable. Reviewing all data is a labour intensive activity and requires both expertise and understanding of the site and its development in the assessment context. An added difficulty is that supporting information is often not reported in scientific literature making judgements as to appropriateness of the data difficult.

Site characterisation cannot guarantee an adequate data basis, since bias can be introduced and all assessment contexts must be covered. However, for many parameters, there are no adequate generic databases available. There is therefore a balance required between use of site characterisation derived data and those available from the scientific literature.

The Posiva programme has not considered sea level rise associated with global warming since this would only serve to slow the timeline for land evolution rather than reverse the process. Release points for radionuclides entering the biosphere are predicted on the basis of fracture zones and hydrological conditions. The majority of discharge points are associated with lakes. However, in low topography areas, some discharge to land or streams may occur: the water table can be on larger areas at a depth of between 0.5 and 1 m, which is within the rooting zone of some plants.

The biosphere assessment is a large part of the overall safety case. To date, a rehearsal safety case has been produced including a biosphere assessment report (Posiva report 2010-03) following

multiple independent reviews. The report is the first comprehensive biosphere assessment completed by Posiva and forms part of the first safety case in 10 years for a KBS-3V repository in Finland. The safety case supporting the construction license application will be produced in 2012.

Regulatory constraints are in place to limit the time period considered by the dose assessment such that many radionuclides will not have reached the biosphere within this timeframe (e.g. radium). Climate-type change considerations are also excluded (i.e. the present *boreal type* is assumed).

A range of modelling tools is used, which enable terrain and ecosystem forecasts to be made. These identify landscape objects from which judgements can be made as the future location of biota. Within the coastline, biosphere objects have been identified that have the potential for direct or indirect receipt of radionuclides. Only a few objects receive direct releases, which together receive 98% of the total release. Distribution of releases between these points is based on the distribution of transport pathways through the geosphere.

The safety case considers a range of realistic release cases. How the ecosystem could develop over time is represented within a single generic transport model, allowing smooth transitions from one ecosystem type to another. Seventy biosphere objects are considered with 166 inter-connected sub-objects. Hydrological fluxes between objects are estimated and used as input to the model.

The landscape model is used to calculate radionuclide concentrations in environmental media within the compartments in each biosphere objects. The concentration in the proper compartment is then used in the dose modelling (for example rooting soil layers in forest objects). Annual dose to a representative person within a most exposed group is calculated. The average annual dose to a larger group is also calculated, as required under Finnish Regulations. This is performed by calculating the number of exposed individuals that can be sustained by the modelled area, taking into account land productivity, availability of land for residences and the availability of drinking water. The distribution of doses between these individuals is the basis of defining the most exposed group and subsequently identify the annual dose to its representative person. The average dose in the exposed population, excluding the most exposed group, is calculated and identified as a representative person for the larger group of exposed people.

Dose to non-human biota must also be considered; however there are issues with regard to the interpretation of dose calculations. It is required that typical doses to representative species are calculated, but Regulators do not provide limits or constraints against which results can be compared. The requirement is rather to ensure that there are 'no harmful effects'. Dose rates in the range 10^{-4} to 10^{-7} µGy/h are typically calculated.

A tiered approach was employed whereby a screening model was initially used to screen out those radionuclides that are of no concern to the biosphere within the assessment time window (10,000 years post-closure). Highly pessimistic assumptions are required to enable radionuclides to enter the biosphere within this time window. Of 34 initial radionuclides, 11 were selected:

- Top priority: C-14, Cl-36, I-129
- High priority: Mo-93, Nb-94, Cs-135, Ni-59, Se-79, Sr-90, Pd-107, Sn-126.

The landscape modelling approach was then employed (considering only the 11 radionuclides above and their progeny) and, finally, annual doses were calculated and compared against regulatory dose constraints. Human dose results were four orders of magnitude below the dose constraint for a representative individual in a critical group and two orders of magnitude below the constraint for doses to a larger group (different constraints are applied in each case).

Following the 10,000 year assessment timeframe, the activity flux from the geosphere is calculated and compared against activity flux constraints given by the Regulators.

The ecosystem type that contributes most to dose varies over time and with end-point. It is not therefore appropriate for the assessment to focus solely on one ecosystem type, such as agricultural land. For the population endpoint, rivers are often the penalising ecosystems (ingestion of water pathway), due to the fact that the most exposed group has consumed all the contaminated food from the most contaminated biosphere object.

For the 2012 biosphere assessment, further scenarios will be developed and a comprehensive set of scenarios is required. This is the focus of ongoing work and is one of the largest challenges in the biosphere assessment methodology.

Discussion

The Finnish regulator requires that the assessment takes account of the most exposed group; in doing this, Posiva assumes that the ICRP critical group and representative person approach are applicable. The most exposed group has to be in the region of the repository and be self sustaining. A lower constraint is applied to the larger population, which is based on people living within a larger region around the repository.

Of the radionuclides considered, Cl-36 is a member of the top priority group. Currently a simple approach is used to model the behaviour of this radionuclide in the biosphere; there may be a need to scrutinise this model against other approaches to ensure it takes account of all relevant FEPs (e.g. interactions with the organic matter pool).

3.7 INHALATION ! THE FORGOTTEN PATHWAY ?

Geert Olyslaegers presented.

The Belgian national waste agency is planning to build a LLW repository at Dessel, near Mol. The project has been running for the last 2 to 3 years.

The community has been actively involved in the design phase and will be involved in the construction of the facility.

All waste will be placed in non-airtight containers (monoliths), which will be placed in modules. A multi-layer cover will prevent rainwater ingress. However, an inspection gallery, requested by the local community, is to be incorporated into the base of the facility to allow for water ingress inspection and contaminant monitoring. In time this inspection gallery will be filled and closed. Any infiltration of rainwater might lead to contaminated groundwater and subsequent cycling through the biosphere. There is also a potential risk from human intrusion into the facility.

Prior to any risk from infiltration into groundwater, there is a potentially small risk from atmospheric releases during the construction and operational phases. This is particularly the case for radon, mostly coming from construction materials. There is therefore a need to ensure that risks from radon remain low – radon has recently received unfavourable media attention thus the community needs to be reassured that the repository will not be harmful even though radon will be emitted.

Radon concentrations have therefore been assessed. With the current design and preliminary source term, between the walls and floor of the facility, radon exhalation rate is 0.0024 $Bq/m^2/s$; above the cover the rate is 0.005 $Bq/m^2/s$ and above the monoliths the exhalation rate is 0.097 $Bq/m^2/s$ (e.g. natural radon exhalations out of concrete is approximately 10^{-5} Bq/kg/s).

In order to calculate impacts on the local community, a combined atmospheric dispersion model, which takes account of local meteorological conditions, and a box model have been employed in calculating radon concentrations outside the facility. Radon hotspots have been calculated for different stages of facility operation:

Stage	Description
1	After filling the first 4 modules (no roof)
2	Closure of modules 1 to 4 modules 5 to 8 are filled (no roof)
3	Closure of modules 1 to 8 , modules 9 and 10 are filled (no roof)
4	Closure of modules 1 to 12, modules 13 to 16 are filled (no roof)
5	Closure of modules 1 to 16, modules 17 to 20 are filled (no roof)
Nearly closed	Closure of tumulus 1 and modules 1 till 8 of tumulus 2, last 6 modules are filled, but still open
Closed	Both tumuli completely closed.

The environment is mostly affected by radon coming from the walls. However, the dose from releases from the walls is 3 orders of magnitude lower than the dose from natural background. The highest Rn-222 inhalation dose is associated with residence between the walls; thus workers are potentially at greatest risk. The calculated effective dose rate between the walls of the repository was 1 µSv/h.

Equilibrium was assumed between radon and daughters. Different residence times were considered for exposure above the facility ranging from 3 to 60 minutes, with the former being considered realistic. A maximum effective dose rate of 0.4 µSv/h for occupancy above the repository cover was calculated.

Overall, the lifetime risks from radon were concluded to be very low.

Other radionuclides were also considered (e.g. C-14 (as methane and carbon dioxide), Se-79, Cl-36 and H-3). It was assumed that the entire inventory was released in a single year and, even for this highly conservative case, doses calculated for each radionuclide were very low; the impact from other radionuclides was therefore concluded to be negligible.

Discussion

The atmospheric dispersion model is unstable for the first 100 m from the repository due to turbulence effects from the structure. At each point at which doses to the local community were assessed, 100% occupancy was assumed.

A clerical typo in units was noted in relation to the background doses and this was to be clarified (e.g. µSv had to be nSv).

A similar study has been performed for the LLWR project in the UK for which radon concentrations in soil gas in the overlying cover have been calculated for the post-closure stage. A scientific paper detailing the regression relationships developed between Ra-226 in soil, Rn-222 in soil gas and Rn-222 in buildings is currently in preparation.

Flux densities could be compared with dispersion model results and would give a feel for the magnitude of impact relating to radium in soils. Radon measurements at the site would also allow more accurate dose predictions, avoiding the necessity of decay product equilibrium assumptions.

3.8 SITE CHARACTERISATION OF THE BIOSPHERE: APPROACHES IN SWEDEN, FINLAND, FRANCE AND CANADA AND IMPLICATIONS FOR FUTURE UK ACTIVITIES

Simon Norris presented.

The RWMD (Radioactive Waste Management Directorate) is part of the NDA (Nuclear Decommissioning Authority). However within a few years, RWMD will become an independent organisation.

Currently, NDA RWMD are undertaking a biosphere site characterisation project and, since no site has yet been selected in the UK, a generic geology is being considered. A review of international site characterisations has been undertaken, focussing upon the French, Canadian, Swedish and Finnish programmes. The objective is to keep abreast of developments in site characterisation and to determine the types of information that are perceived to be relevant and the techniques by which such information could be acquired. This information will be applied to the UK site characterisation programme once a site (or sites) has been selected. The review is documented in a draft NDA RWMD report [QRS-1378W-3]. Data gathered will be used to inform the environmental impact, operational safety and post-closure safety assessments.

A previous Nirex study illustrated data acquisition requirements for sites. This is being built upon by the current study. Various accessible documents have been reviewed from the French, Canadian, Swedish and Finnish programmes.

The French programme is focused around a site that has not previously been used for nuclear activities thus a comprehensive study is required in order to determine the current baseline. The Swedish, Finnish and Canadian sites are all close to existing facilities so baseline data were already available. Supporting data were however required.

Considerable commonalities were observed between the programmes, but notable differences were evident. For example, landscape evolution dominates the Scandinavian programmes whereas considerations of fluvial erosion and sedimentation are the main influences for the French programme. The environmental impact assessment is the focus of the Canadian programme.

In both Sweden and Finland, a staged approach to site characterisation has been adopted with comprehensive reports being produced during data freeze periods. In France, no defined data stages or programme stage gates for report production have been defined.

From the SKB programme it is evident that a vast amount can be achieved over a relatively short timeframe. Techniques are readily available for site characterisation; however, the main limiting factor is the availability of human resources to deploy the techniques. A clear plan for site characterisation was produced prior to work commencing and there was a clear commitment to detailed reporting which required different disciplines (e.g. data gatherers and data interpreters) to work in close collaboration. Uncertainty analysis is used to help prioritise work.

The Posiva programme has clear similarities to the SKB programme, but a greater continuity in reporting is observed. The programme clearly illustrates the close links required between site characterisation and model development. A clear emphasis of the programme on determining standing biomass densities and stable element concentrations to determine fluxes and pools is

observed. There does not appear to have been much effort placed on nuclear sites in the vicinity of the repository site to provide site characterisation data. A formal knowledge quality assessment process is in place.

The Andra programme was first focused on baseline surveys which relate to the requirements of an environmental impact assessment. Subsequent studies have focussed on geomorphological investigations to determine how the site has evolved to the present day and thus how it may evolve in future. The importance of focusing on the regional scale or smaller for landscape development was noted. The programme is focused on the development of both descriptive and numerical models.

The Canadian programme is driven by the requirements of EIA, with a primary focus on the present day system.

From the review it was concluded that, in going forward, there is a need for careful planning in advance, and the attention must be paid to data quality assurance and archiving. Good communication must also be maintained between disciplines and that there must be a well defined categorisation of data for reporting purposes. All data collection and interpretation programmes are strongly driven by model requirements, which are themselves related to the nature of the specific sites under investigation.

Discussion

Many of the differences observed in the site characterisation programmes arise from differences in the sites themselves. For example, land evolution is evident in both Finland and Sweden whereas the Canadian Shield is very stable. However, other differences arise from national regulatory requirements. Since the UK programme is currently site generic, a wider range of site characteristics must be considered in moving forward. This can then be focused when site(s) are selected. By reviewing international practise, the UK programme can be developed in a joined up manner and then focused on identified sites. By planning prior to site selection the programme can be implemented rapidly and reduces planning requirements once the (intensive) programme is underway.

3.9 HOW TO INCREASE CONFIDENCE IN THE RESULTS OF BIOSPHERE MODELLING – WHAT CAN WE LEARN FROM PAST AND PRESENT?

Gerhard Prőhl presented.

The key problem with biosphere modelling for repositories is that we anticipate that releases of radioactivity will occur to the biosphere, but these will occur in the far future. However, there is a need to demonstrate compliance thus exposures and risk must be predicted.

The IAEA is currently working on a safety guide: Safey Case and Safety Assessment for Radioactive Waste Disposal. This will recommend that numerical assessments are taken into account, but will also encourage assessors to go further by incorporating qualitative and quantitative considerations and by exploring the limitations of models. The intention is to make assessments more understandable to the public by giving simple, robust and plausible arguments.

The goal of assessments should be the protection of people – not aliens. All people have three basic requirements – to eat, to breathe and to drink. Food consists of plant and animal products. Plant and animal physiology will remain more or less the same over time, although some evolution over timescales of millions of years would be expected. Overall, however, similar characteristics would be envisaged. For people, no fundamental changes in physiology or sensitivity should be assumed.

A likely release scenario is that radionuclides enter the geosphere in deep groundwater and migrate to the near-surface groundwater. Entry to the biosphere is through either natural groundwater upwelling, which can result in soil contamination, or abstraction of groundwater from a well. The well water abstraction scenario leads to direct pathways to humans (e.g. drinking water) plus indirect pathways (irrigation of crops, drinking water for agricultural animals).

The important transfer processes include irrigation rate, uptake from soil, translocation, weathering etc. Such processes are influenced by factors such as climate, soil and technology. Some, but not all, processes are universal. All processes tend to be closely linked; thus system considerations are complex.

If global land use is analysed, it is evident that the majority of available land is not used for agriculture; rather much of the land area is comprised of desert. Global precipitation and primary production are linked and are the key components determining land use. The highest rates of primary production are associated with tropical rainforests whereas the lowest rates are associated with extreme desert areas. Most temperate areas have relatively low productivity, as indicated below.

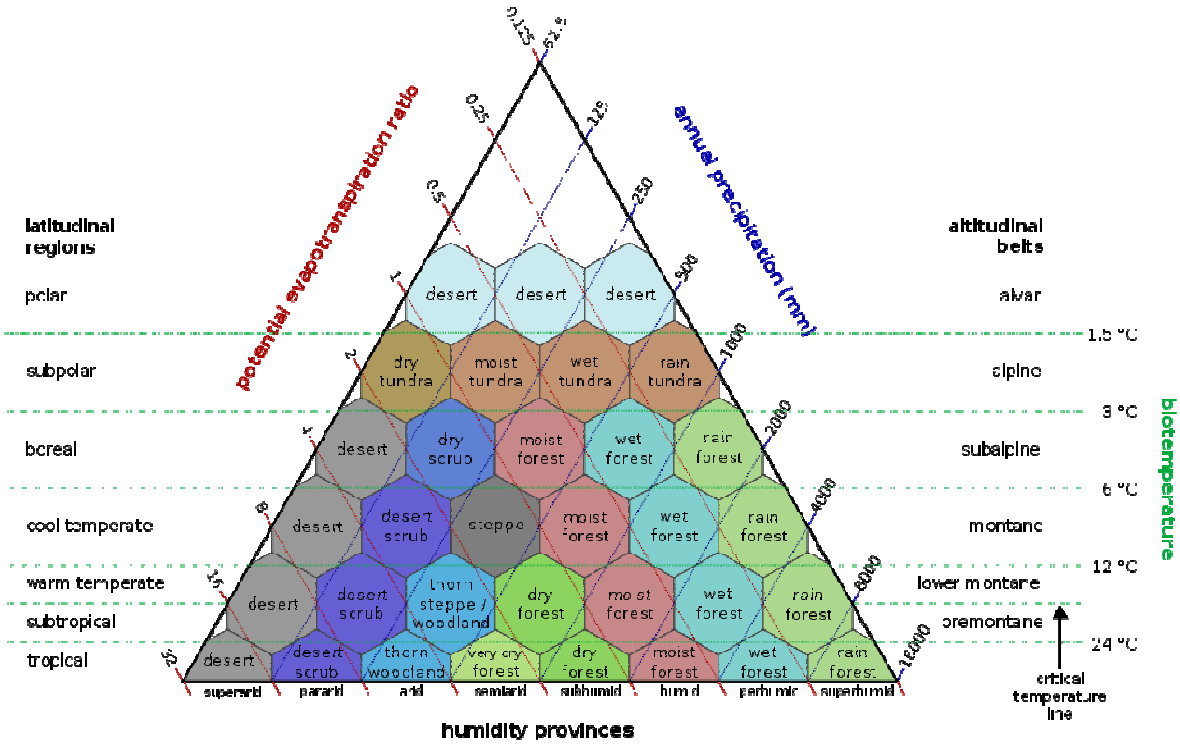
Dry matter net productivity and dry matter biomass inventories of different ecosystem types

Ecosystem	Net assimilation ($g\ m^{-2}\ a^{-1}$) [a]		Biomass ($kg\ m^{-2}$) [a]		Turnover (a^{-1})
	Typical value	Range	Typical value	Range	
Tropical rainforest	2200	1000-3500	45	6-80	0.020
Green monsoon forest	1600	1000-2500	35	6-60	0.022
Temperate rainforest	1300	600-2500	35	6-200	0.027
Deciduous forest	1200	600-2500	30	6-60	0.025
Boreal forest	800	400-2000	20	6-40	0.025
Savannah	900	200-2000	4	0.2-15	0.0044
Temperate veldt	600	200-1500	1.6	0.2-5	0.0027
Tundra	140	10-400	0.6	0.1-3	0.0043
Semi desert	90	10-250	0.7	0.1-4	0.0078
Extreme desert	3	0-10	0.02	0-0.2	0.0067
Agricultural land	650	100-3500	1	0.4-12	0.0015
Bog, marsh	2000	80-3500	15	3-50	0.0075
Rivers, lakes	250	100-1500	0.02	0-0.1	8,0E-05
River mouth	1500	200-1500	1	0.01-6	6,7E-04
Continental shelf	360	200-600	0.01	0.001-0.04	2,8E-05

Open ocean	125	2-400	0.003	0.005	2,4E-05

[a] The carbon content of dry matter is about 50 %; therefore the total amount of carbon fixed during photosynthesis is equivalent to the net assimilation.

The Holdridge Life Zone Climate Classification (shown below) combines annual precipitation, evapotranspiration and humidity. For any combination of these, vegetation types are detailed. In humid (high rainfall tropical) environments then rainforest is always found. Dry tropical environments are all represented by desert vegetation. The form of vegetation is therefore determined by water supply and latitude.



The form of vegetation present in an area can be influenced by humans, but again trends are evident. In polar desert regions there is minimal land use; more intensive land use is evident in moving toward more temperate and tropical climates. In dry temperate regions there is dry farming and extensive grazing practises are evident.

Soils have largely developed since the last ice age thus the general age of soils is some 15,000 years. Older soils are present in tropical regions that were not affected by glaciation. The upper horizon of soils (the A-horizon) is typically between 10 and 1,000 years old.

The speciation and mobility of radionuclides in soils depends on sorption capacity and pH/redox. Soil management activities are aimed at optimising plant growth and practices therefore aim to meet optimal targets for organic matter content, pH, nutrient concentrations, soil aeration and water retention/drainage. Redox, pH and soil water are closely inter-related. The natural form of the soil will determine the amount of human interference.

If the development of soil and climate is considered from a global viewpoint, a relationship is evident between the weathering depth of soil and climate. In Polar regions the weathering depth is low whereas in temperate climates much greater weathering occurs due to climatic factors such as increased rates of precipitation. Low weathering is again observed in dry tropical areas, but higher rates occur in tropical rain forests. Weathering is related to other important processes such as the leaching of calcium and silicates.

In order to address climate in safety assessments over the long-term, it is important to consider climatic cycles. However, the present day environment provides many analogues for each of the climatic conditions that could occur at any given site. These analogous climates allow seasonality to be studied, including temperature ranges and the effect on soil water deficit, taking into account precipitation rates. Therefore, although we may not know the future climate accurately, it is possible to illustrate how possible future climates would impact on a site through the use of such analogues.

Food intake studies have been undertaken in Germany to determine the main foods consumed (from food basket studies) for analogue sites representing different climatic conditions. This study provides relevant information on how intake rates vary for different food groups with climate.

It was therefore concluded that radionuclide transfer processes are universal and are greatly influenced by agricultural practices which are themselves largely determined by climate. There are large uncertainties associated with extrapolating from current conditions to the future and such extrapolations are highly speculative. Therefore, in order to increase transparency and traceability, any future climate conditions should be compared against current analogue sites for which parameter values and boundary conditions can be investigated. It is considered that such an approach would greatly facilitate stakeholder communication; enabling predicted changes in human and environmental behaviour to be clearly demonstrated on the basis of current analogous sites.

Discussion

In Scandinavia, information relating to the last glacial cycle is being applied in order to demonstrate what may occur in the future. The use of such historical information is considered very useful and is a technique that could be used elsewhere.

In addition to trying to assess the form of future biosphere objects, it is also important to consider other processes that affect the accumulation of radionuclides. Simple models are often used for such predictions and, where these are employed, why parameters and approaches have been selected needs to be clearly documented. This is where the use of analogue sites could be valuable by providing additional supportive material for modelling studies. The history of a site is also a good analogue for future climatic cycles.

3.10 NEW TRANSFER FACTORS TO FISH, WILD GAME, DOMESTIC ANIMALS AND CROPS

Steve Sheppard presented.

Stable element transfer factor work has now been completed and is reported in NWMO report TR-2009-35. The work initially focused on iodine analysis using ICP-MS, but was expanded to include a total of 50 elements. A range of parameters have been determined, including:

- Fish concentration ratios;
- Plant concentration ratios;
- Transfer factors from vegetation to animals;

- Soil Kd; and,
- Concentration ratios for honey in relation to pollen.

The study largely focused on the southern Precambrian shield and took account of coastal influences.

In 2006, the concept for measurements was demonstrated. This was followed in 2007 by collection and analysis of a range of samples (e.g. deer, geese, fish and blueberries). To determine animal transfer factors, the stomach content was used as a substrate. The programme was further extended in 2008 and 2009.

Results for iodine demonstrated a variation in fish concentration factors with lake. The programme served to substantially increase the availability of data for iodine; 36 new data were added to the 21 found in available literature. When compared with literature data, the geometric mean (GM) did not vary, but a much greater database supported the analysis. A weak relationship was observed between fish and macrophyte concentration data.

In the case of iodine Kd, the median value was shifted from that derived from literature data.

Overall it was concluded that stable element analysis was particularly useful for aquatic samples, enabling steady state parameters to be derived. The analysis is relatively cheap when compared with spiked samples and can be conducted on reference environments rather than under controlled conditions. The method would also allow different species to be compared and can be supported by literature data.

Interesting correlations were observed for terrestrial animals (e.g. deer and moose). In the case of domestic animals, a range of organism sizes were selected for analysis (e.g. rabbit to moose, pigeon to turkey). Literature data were minimal for birds (only 2 references are available for iodine) and the study served to increase the database by a further 12 values.

The IAEA EMRAS programme was running in parallel to the study and the derived transfer factors have therefore been compared against the stable element data.

For milk, most radionuclides were the same, but differences were observed for Nb, Zr, Fe, I, Mn and U. In the case of iodine, the differences may relate to the use of iodine as a teat dip which may introduce bias in the stable element samples. Similar deviants were observed for eggs.

For beef, the majority of radionuclides were similar between the stable element data and those derived within the EMRAS programme.

A review was made of the geometric standard deviations relating to both animal concentration ratios and daily transfer to meat (TF). The geometric standard deviation (GSD) was found to be greater for TF than for CR suggesting less confidence in the TF interpretation of the data. Correlations were also investigated for different animal concentration ratios. Beef concentration ratios were found to be well correlated with those for meat of birds, swine, rabbits and lamb. It was therefore suggested that a move to concentration ratio rather than TF in model studies would allow for more consistency.

For honey, plants in bloom were analysed and pollen was retrieved from bees. Honey concentrations were also analysed. Overall, a reduction in stable element concentrations was observed throughout the honey production process.

For crops, a lot of noise was observed with the data, particularly at the lower range of the concentration scale suggesting there may be a detection limit issue. It was suggested that this may

arise from resistance of some soil particles to washing in leafy crops. Concentration ratios below 10^{-3} are therefore likely to represent soil adhesion processes rather than root uptake.

A correlation was also observed between Kd and CR. However, both essential and non-essential elements had to be plotted separately. Interestingly, Mike Thorne noted that in work done for the PRISM model the relationship between soil moisture and Kd was investigated with the conclusion that there were two values – one for essential and one for non-essential elements.

In 2010, the work programme aims to look at environmental increments (i.e. increases above background). Background concentrations were reviewed in 2009 and a number of data gaps were identified thus the aim in 2010 will be to address some of these gaps. This will largely be done using accelerator mass spectroscopy. Primordial radionuclides and the disequilibrium between parents and daughters will be investigated, largely in relation to surface waters around Ontario. Tundra lakes and soils from the sedimentary basin will be included.

Discussion

New sediment Kd data were higher from that published previously. This is likely to be due to the fact that the new data were for stable elements whereas older studies may have been from tracer studies. The type of sediment and the way it is sampled would also affect Kd.

3.11 RESULTS OF A SAFETY ASSESSMENT OF A GLACIATION SCENARIO FOR A USED FUEL REPOSITORY

Frank Garisto presented.

Since 1995, three safety assessments have been conducted for a Canadian repository. Different sites have been considered and both radiological and toxicological impacts have been taken into account. Since the sites considered are inland, there is no consideration given to land uplift; the landscape remains relatively constant. Climate, however, has not been constant in Canada; thus glaciation will be of particular relevance over the timescales being considered. The overall goal is to quantitatively assess the effect of glaciation on long-term safety.

The basis for the safety assessment is a defective containment scenario whereby undetected defects in canisters lead to an early release of radionuclides. The repository (hypothetical at this stage) would be located in the Canadian shield at a depth of 670 m. Copper fuel canisters would be emplaced in horizontal boreholes. Hydraulic conductivity of the rock and fracture zones vary with depth.

Models have been developed to recreate plausible histories of past glacial events. Warm-based glacial transport is assumed (i.e. there is water at the base of the glacier) and the glacial cycle lasts for around 120,000 years. This cycle is used to represent what may happen in future cycles. The current inter-glacial period has been assumed to last a further 50,000 years. It is anticipated that, in future cycles, permafrost could be up to 300 m deep at the repository site. In order to simplify the glacial cycle and permafrost depth, a step function was used in the model.

Groundwater flow is modelled using FRAC3DVS. Transport modelling aims to calculate radionuclide mass flows to the biosphere following release from defective canisters.

Glacial cycles modify the flow field extensively, but most changes occur at shallower depths thus the cumulative impact of repeated cycles is cancelled out. Most releases are to lakes and wells. For iodine, peak releases are predicted to occur during temperate periods. Concentrations in lakes are likely to be lower than in wells.

The biosphere model incorporates various climate states (temperate, permafrost, proglacial lake states). For each state, a different critical group has been identified. In a temperate climate, the critical group consists of a self-sufficient farmer family, which make use of well water. When ice sheets are present there would be no people present so no doses are calculated. For the proglacial lake state, rapid melting of ice leads to the formation of a large water body, which has a shoreline of ice. The critical group consist of fishermen that have a large fish intake, but also hunt caribou. The lake is assumed to be located directly above the repository. Hunting and fishing are not pathways considered for the self-sufficient farmer critical group.

For the reference base case, the highest doses were calculated to occur during temperate conditions when well-water is used. I-129 is the key radionuclide contributing to dose, followed by Cl-36. Calculated doses are below the ICRP dose constraint of 3.10^{-4} Sv/y. During glaciation scenarios, dose rates were a factor of 3 higher when compared against a constant climate scenario. During permafrost, the main dose pathway is the ingestion of animal products due to the lichen-caribou-human pathway, followed by drinking water. Lichen contamination is assumed to be constant, irrespective of the distance of lichen from the repository. The important pathways vary with stage in the glacial cycle.

Sensitivity cases have also been run to determine the impact on dose calculations. These have included no-well scenarios and a scenario whereby all canisters fail simultaneously after 100,000 years, which is the minimum lifespan of a canister. When no well is assumed to be present, doses are substantially reduced. If all canisters were to fail at 100,000 years, the dose constraint would be exceeded; however, this is a highly pessimistic scenario with a very low probability of occurrence.

Discussion

The greatest doses for the glaciation cycle occurred in the periods following permafrost. During permafrost conditions, radionuclides are unable to reach the biosphere, but migration occurs once the permafrost melts. Permafrost therefore affects the groundwater flow fields. Instantaneous changes to the geosphere properties as a result of the glacial cycle could have a large impact on dose calculations.

Previous assessments (e.g. within the Nagra programme) were unable to consider periglacial phases due to a lack of relevant supporting data. Norwegian data was used in the current study.

Morphological impacts of glaciation were not considered in the present study due to the unlikelihood of glacial erosion exceeding 2 m depth.

For the lichen-caribou-human pathway it is assumed that caribou remain within the area long enough for iodine concentrations to equilibrate and that enough caribou are harvested and stored to meet annual consumption demands.

3.12 THE SE-79 STORY: LITERATURE REVIEW AND MODEL DEVELOPMENT

Mike Thorne presented.

Studies relating to Se-79 have been undertaken on behalf of the NDA (RWMD) and CIEMAT. For NDA (RWMD) a draft review report has been produced, which considers:

- Chemical and physical characteristics of selenium and implications for modelling;
- Transport through the geosphere-biosphere interface;

- Transport in soils and uptake by plants;
- Uptake and retention in animals;
- Transport in freshwater systems and uptake by biota;
- Transport in estuarine and marine systems and uptake by biota;

How these processes are representation in assessment models is considered.

Sensitivity studies were also undertaken as part of the review, using an NDA spreadsheet programme which focused on selenium model parameters. Radionuclide independent components of uncertainty were not studied in this case.

Two reference cases have been used; one considers groundwater discharge to an agricultural soil in a temperate environment and the second considered well abstraction for irrigation purposes. Relatively high soil-plant transfer factors and plant-animal transfer factors lead to the consumption of animal products being dominant in terms of dose. Suppressing plant uptake or animal uptake leads to a decrease in the calculated doses for a given exposure scenario.

There has been uncertainty over the half-life of Se-79 which has been resolved for radiological assessment purposes by the adoption of the value of 2.95E5 years in ICRP Publication 107.

Uncertainty relating to Kd and the effect of foliar uptake were also investigated. A correlation was noted between Kd and soil:plant concentration ratio. When one increased, the other decreased. The concentration ratio was computed by specifying a delta value and effective soil volume. A discrimination factor is applied for essential/non-essential elements. Results from the sensitivity studies were in general, no more than one order of magnitude higher than the reference case values. If lower transfer factors for animals are assumed then results could be between 1 and 2 orders of magnitude lower than the reference case.

Work conducted on behalf of CIEMAT involved the development of a model for Se-79 in the soil-plant system. Hydrology was represented by a 1-dimensional vertical model and a mass balance approach whereby precipitation is balanced against losses.

The Kd for selenium is different above and below the water table and this impacts upon Se-79 migration. In parameterising the model, the capillary fringe and depth of the water table were used as a surrogate for redox. Soil layers can occur above or below the capillary fringe. No assumptions are made as to the thickness of soil layers in relation to the position of the capillary fringe.

Selenium is particularly interesting due to its redox sensitivity; the degree of soil sorption is very dependent upon the oxidation state. Volatilisation may also be important and is assumed to be microbially controlled, thus will be influenced by water availability; there will be a balance between soil moisture requirements for microbes and low soil moisture levels to enable gas to volatilise from soils. Soil water content must therefore be determined in order to represent volatilisation within the model.

Ten soil layers are represented in the model with water flows between. Selenium migrates with the flow of water, but may be retarded by sorption to soil. Kd is allowed to vary depending on the position of the soil compartment relative to the water table. Kd is reduced in summer due to soil drying. Evapotranspiration is taken into account.

Selenium volatilisation was considered in sensitivity studies of the model. Fluctuations in the water table had a relatively minor affect on the overall accumulation of Se in soil. A time series of volatilisation rates in relation to soil water changes was observed.

Uptake of Se-79 by plants is also dependant upon the water content of soils. The model considers root density, depth of soil and includes a function that varies the effectiveness of root uptake in relation to soil water content. If the water table rises above the lower roots of a plant, uptake by these roots will be substantially reduced and is suppressed in the model through use of a function that depends on the degree of saturation.

Plant losses are represented by rate constants for volatilisation, cropping etc. There is a single compartment for organic matter in plants. This organic matter can be returned to the soil sink and is redistributed between soil layers before being subject to mineralisation. Recycling is therefore represented.

A simplified approach to soil hydrology can therefore be used to estimate seasonally varying water content and fluxes in a multi-layer soil model. That model can be used to inform a model for Se-79 transport in soils and uptake by plants that takes into account the effects of changing soil water content on sorption, volatilization from soil and root uptake. The model is currently implemented in AMBER, but could be implemented in other simulation packages.

Sensitivity studies have indicated that results appear sensible. The model could provide a suitable method for determining future Se-79 research priorities.

Discussion

Andra and others have models that consider the water table and different soil zones and comparison of these models may prove interesting.

The CIEMAT model has not been validated against real data as yet. Limited data are available from Imperial College column experiments and this could be used for validation purposes.

3.13 SE-79 MODELLING OF THE SOIL TO PLANT SYSTEM FOR SPANISH CONDITIONS

Danyl Perez-Sanchez presented.

A model (outlined in the presentation summary above) has been developed by Mike Thorne to represent Se-79 behaviour in the soil-plant system, and consideration is being given as to how this could be applied to Spanish sites. Within the model, soil is divided into 10 compartments and water flows through each are calculated. Although developed for Se-79, possibilities for the model are broad; it could be applied to other radionuclides, including the uranium decay series.

The model requires the following parameters:

- Time series of potential evapotranspiration;
- Time series of precipitation;
- Depth to field drains and their location;
- Depth to the water table;
- Saturated hydraulic conductivity for each layer; and,

- Saturated and residual water content for each layer.

Climate defines the distribution and productivity of vegetation.

Mean monthly values for precipitation and potential evapotranspiration have been collated for Spain and have been used as input to the model; a large variation in the saturation of soil layers was noted with season. Once soils are completely dry, full re-saturation can occur within a period of around 100 days. Moisture excess in soils relates to precipitation and evapotranspiration and may also be linked to groundwater discharge.

In order to validate the model, there is a need to determine what the real behaviour of selenium is within Spanish soils. The Iberian Peninsula has some very distinctive precipitation regimes (in terms of annual rainfall patterns) and some good data for climate are available for the Tajo river catchment due to uranium mining activities in this region. Meteorological conditions for Spain were also considered within the IAEA BIOCLIM project and these data will be employed.

Irrigation is an important process in Spain and must be linked with climate. However, irrigation is not included within the model at this time; it is hoped that the FAO methodology for calculating irrigation rates can be incorporated. To run the model for different climates, supporting data are required and the types of soils, soil characteristics and crop production must be identified. Sensitive parameters can be identified within the model for which better data are required. By focusing on these data, the model can be improved.

Discussion

For future estimates, mean monthly meteorological data from monitoring stations around the world are available and could be used as analogues for different climate conditions.

3.14 RADON AND DISEQUILIBRIUM IN THE URANIUM-SERIES DECAY CHAIN

Maryla Wasiolek presented.

Disequilibrium in the uranium decay series is an issue, particularly in relation to radon. The issue stems from the way in which long-lived radionuclides are assumed to migrate through the saturated zone to the point of withdrawal (e.g. agricultural well) and the assumptions that are made with regard to decay products. Assumptions generally work well for long-range transport, but well capture zone retention times are sufficiently long for disequilibria to occur within the decay chain. Disequilibrium is observed between the radiologically significant Ra-226, Rn-222, Pb-210 and Po-210. The differences observed result from differences in the sorption of elements onto rocks in the local area such that radionuclides may be in equilibrium throughout the rock system as a whole, but not in water abstracted from that rock. It is sometimes inappropriately assumed that Rn-222, Pb-210 and Po-210 are in equilibrium with the Ra-226 in the water, because that is the result from the models for radionuclide transport in the geosphere, which do not address the shorter-lived radionuclides.

Radon is a non-sorbing element which is a daughter product of Ra-226. Radium can sorb onto rocks and will produce radon that is free to diffuse into water. Concentrations of radon may therefore be greater than those of Ra-226 within groundwater, for example, by up to three orders of magnitude. Whether this matters or not depends on how quickly the water is used after abstraction. Noting the 3.8 day Rn-222 half-life, in large municipal systems there is not usually an issue since there is time for the radon to decay before the water is used. However, where water is abstracted directly for agricultural use or small scale household use, such decay may not occur. If radon is present in water used for spray irrigation then a rapid release of radon to atmosphere would be expected. Any not released

during the irrigation process itself may be released from soil water. If people are present during the irrigation period then inhalation doses may need to be considered (including inhalation of short-lived decay products).

Many of the decay products of radon are important external dose contributors. It is common practice for these to be assumed to be in equilibrium with radium thus concentrations may be underestimated. This could be an issue when orphan radon is applied to agricultural land through irrigation. In such circumstances the radionuclides would be close to the surface of soils such that impacts to anyone standing on recently irrigated soil may be important.

Indoor uses of water may also pose problems such as the use of evaporative coolers, which are routinely used in southwest America where the climate is dry. These coolers pump air through a porous medium with recirculating water to which water is continuously added. In such instances it could be assumed that 100% of the radon in the water would enter the air. However, there is a large exchange of air when such coolers are operating and this would have to be factored into any dose assessment.

If water ingestion occurs straight from the well then radon ingestion may need to be considered. Where radon is in equilibrium with Ra-226, ingestion dose is not an issue since the key factor for dose is Ra-226 ingestion. However, if radon concentrations are substantially higher then further consideration may need to be given to this pathway.

Discussion

In many assessments, cautious assumptions are made for one reason or another. However, it is not always obvious what makes an assumption cautious. What may lead to higher dose estimates for one radionuclide may result in lower dose for its radioactive progeny.

4. UPDATE ON INTERNATIONAL PROGRAMMES

Gerhard Pröhl is responsible for the IAEA EMRAS II programme on environmental modelling for radiation safety. The IAEA acts as the host, bringing together people from different disciplines that are interested in modelling radionuclide environmental transfers and doses.

The EMRAS II programme was launched in 2009. There are three main work programmes:

- Reference approaches for humans;
- Reference approaches for non-human biota;
- Reference approaches for emergency situations.

For the last case, consideration is given to the dispersion of radionuclides in urban environments resulting from terrorist activities.

The non-human biota group is concerned with data collection, the application of models and effects on populations.

The reference approaches to humans has three groups:

- Discharge model comparison;
- Radioactive waste disposal;
- NORM sites and legacy wastes.

Information from the latter two working groups was presented.

4.1 EMRAS II WG2 NORM AND LEGACY SITES

Danyl Perez-Sanchez presented.

The NORM and legacy sites working group has numerous participants from different countries. Many different sites are being considered that have diverse geographical situations. The issues from legacy sites and NORM sites are essentially the same.

Presently there are not enough environmental monitoring data to allow for wide-ranging model inter-comparison studies. Therefore the aim is to compare models for specific situations and to develop guidance. Two tasks will therefore progress in parallel: general assessment methods and trial application.

The working group has links to BIOPROTA through the U-238 series project for which similar radionuclides are of interest. The development of an understanding of the disequilibrium throughout the decay chain will be important.

4.2 EMRAS II WG3 SOLID RADIOACTIVE WASTE

Tobias Lindborg presented.

The objective of the solid radioactive waste working group is to develop reference models for waste disposal, thus taking a step forward from the BIOMASS project.

Two working group meetings have been held to date.

In January 2009, the initial meeting was held at which the objective was to develop work plan. Considerations were given to work previously undertaken and how models considered climate change. Three topics were identified as a result of the meeting; the objective is not to repeat work previously undertaken but rather to progress this further.

The second meeting further progressed the work plan. A number of sub-groups have been formed. The first is focused on analogues – how present day analogues can be applied to site assessments for future climatic conditions. The second considers soil-plant processes. The third group looks at dynamic representation of future biosphere systems with a focus on Scandinavia. Demonstrating compliance with protective objectives is the focus of the fourth group, in which regulators are participating.

The objective is to produce an interim report by the end of 2010 that will address the progress in relation to the overall work plan. A third meeting is to be held in Munich in October 2010. All interested parties are invited to attend and contribute.

4.3 IUR WASTE WORKING GROUP

Mike Thorne provided an update on the activities of the IUR Waste working group.

The aims of the group are to promote cooperation between radioecologists and those concerned with long term dose assessment for releases to the biosphere, and to identify and address data gaps. Throughout there has been an awareness of the need to avoid overlap with the work being undertaken within the BIOPROTA programme.

A meeting was held in 2009 which focused on improving interaction matrices for a number of radionuclides, including a joint meeting with BIOPROTA to develop an interaction matrix for Se-79 for the soil-plant system.

Since this meeting, little progress has been made. The future focus will be on reviewing the interaction matrices and to develop recommendations for model improvements.

5. FIELD TRIP TO SKB FORSMARK SITE

SKB arranged a substantial excursion for participants to visit the Forsmark, where there is already a nuclear power station and a repository for low and intermediate level solid waste (SFR), and it is planned to develop a high level waste repository.

The excursion included a visit to the SFR and components of the biosphere, arranged through the day in a logical progression which reflects the anticipated evolution of the biosphere, starting with the coast and working inland. Explanations were provided of the key features of the environment, the scope for environmental change, and the on-going work to characterise the biosphere system through various measurements and observations.

A substantial excursion guide was provided by SKB, illustrating how site characterisation work is linked to the biosphere assessment work within the overall safety case for the proposed HLW repository. SKB has kindly agreed to make the guide available via www.bioprota.com

Below is a scene of the current coast:

which, given local land uplift, is expected to see the development of lakes:

subsequent development of bogs and mires as lakes are filled with mineral sediments and organic matter:

and eventually, forest.

SKB staff were on hand to explain the site biosphere characterisation programme, as illustrated above, and answer queries about how the data are interpreted and used in the safety assessments currently being developed. The opportunity was taken for a group photo, below.

6. THE 2010/11 BIOPROTA WORK PROGRAMME

A number of tasks are ongoing in 2010/11 and proposals have been submitted for further projects. In addition, further proposal ideas have been generated as a result of the workshop. These are outlined below and relevant actions identified.

6.1 DEVELOPMENT OF GUIDANCE FOR INTERPRETING DOSE ASSESSMENTS TO NON-HUMAN BIOTA

Karen Smith presented.

Over the last few years a number of tools for NHB assessments have been developed.

The methods that are available for calculating dose rates to NHB are cautious and there is a question as to whether the degree of caution inherent in these methods is consistent with the caution required in performance assessments. Some of the tools (e.g. ERICA) offer a tiered approach, but it is not always possible to apply lower assessment tiers due to inconsistencies between the radionuclides of interest and those included in the assessment methods.

Currently, no internationally agreed screening criteria or standards for environmental protection are available. No guidance is available as to the appropriate response when screening criteria are exceeded beyond carry out some basic research. Issues also arise in NHB assessments with regard to the interpretation of regulatory requirements. For example, in Finland there is a requirement to demonstrate 'no impact on biodiversity'. No guidance is provided as to how this should be demonstrated. Interpretation of model results, as much as the dose calculation, forms part of the overall NHB assessment.

The objectives of the proposed work programme are therefore to develop a considered and defensible consensus approach to situations where NHB screening levels are exceeded and to provide guidance for other regulatory endpoints. The intention is to work both with operators and regulators in the development of this approach through a questionnaire consultation and workshops. Those involved in the development of current approaches would also be consulted. Where possible,, current approaches will be built upon. The way in which regulatory compliance is demonstrated in relation to environmental protection objectives for nuclear power plants and other industries would be reviewed.

Input to the project will include an NDA-RWMD report[a] which provides a review of the basis for current screening approaches. The BIOPROTA NHB uncertainties report will also provide input to the study.

The work programme will aim to produce recommendations for NHB assessments for radioactive waste disposal facilities in the form of a report detailing:

- the approach (or approaches) for interpreting assessments where screening levels are exceeded;
- approaches for compliance demonstration, taking into account the range of regulatory criteria (biodiversity / sensitive species); and

[a] Smith K, Robinson C, Jackson D (2010). Basis for, and implications of breaching, proposed screening levels for biota dose assessments. Enviros report to NDA (RWMD), NU0160020, Draft.

- remaining uncertainties / limitations and recommendations for how to address them.

An updated proposal will be distributed to potential sponsoring organisations for consideration in the summer, taking account of the final results from the current project reported at Section 2.2.

Discussion

It is a regulatory requirement for NHB assessments to be undertaken in a number of countries, including the UK, Finland, Sweden and Canada. There is no regulatory requirement specific to radioactive waste repositories at this time in either Switzerland or France.

A new ICRP Task Group was established in March. The first meeting of this Task Group will take place in Helsinki in June. One of the objectives of the group will be to consider how human and NHB protection can be combined. Many of the issues raised in the presentation will be addressed by this group. However, the current work plan is aimed at providing guidance as an interim measure, prior to the provision of further guidance from the ICRP.

6.2 C-14 LONG-TERM DOSE ASSESSMENT – PHASE 2

Laura Limer presented.

A proposal was circulated in 2009 and many organisations have agreed to participate. The objectives are to address some of the remaining questions arising from the phase I project and to further investigate the scientific basis between modelling approaches. Quantitative comparisons will be undertaken and account will be taken of new experimental and field data. Posiva is funding the University of Eastern Finland to participate, which enables both models and data to be considered from the outset. In Sweden, both the operator and the regulator are participating.

It was noted that the LLWR in the UK has built upon the work conducted under phase I to develop a model which considers canopy mixing and dilution and can evaluate releases of C-14 as carbon dioxide or methane. The model has seven above-soil compartments to allow the effects of different vegetation types on the canopy atmosphere to be considered. The model has been implemented as a test version in AMBER and will be used to investigate sensitive parameters.

A two-day workshop, hosted by EdF, took place in February 2010, which was attended by 16 participants from 6 countries, representing a range of operators, regulators, researchers and technical support organisations and a larger grouping than had been involved in Phase 1. Various presentations were made on plans for future field work in the UK and France and model and assessment developments.

The key conclusion from the workshop was that simple analytical comparisons of models should be made to determine whether or not the equations within each of the approaches are comparable. It was also agreed that a FEP analysis would be undertaken from a blank canvas to determine what the processes are that should be included in models. This analysis is used to determine the features (e.g. components of the site), events (which may or may not happen, such as climate change) and processes of importance for C-14 modelling. This analysis has been completed, on the basis of the BIOMASS methodology, and an interaction matrix produced. FEPs are referenced to their location within the interaction matrix; any excluded FEPs are clearly documented with reasons provided. Both water and gaseous inputs to an agricultural system were considered. Where processes may differ for other systems (e.g. forests) these are identified. Processes occurring within different soil layers are considered within more detailed interaction matrices that detail how the soil layers interact.

A draft report on the FEP analysis and interaction matrix is due to be distributed shortly to project participants and sponsors for comment. The future work programme will include an analytical comparison of models; the document detailing the LLWR model development will be distributed. The BIOPROTA interaction matrix will also be compared with those produced elsewhere (e.g. IUR).

Discussion

A large international project, NOPEX, has looked at international measurements for carbon exchange in fields, forests and different climates through multiple measurement stations and has developed exchange rate computational methods.

Positive comments were raised with regard to the LLWR model and the FEP list/interaction matrix presented. However, it was noted that intensive experiments on carbon metabolism in plants have been conducted over many years. It was therefore suggested that some of the questions raised may already have been addressed. However, although these may have been addressed, the context will be different from that being considered in the current project. Although a large database is available, these data have not been generated for the purpose of long-term model development; many data will be representative of atmospheric releases.

It was suggested that a global model could be employed to address photosynthesis per year, the amount of carbon in soil and degradation of carbon in soils, which are key processes over the long-term. Not all organisations are interested in C-14 in the long-term however. For example, the LLWR is interested in the next thousand years; after 10,000 years most of the C-14 in the repository will have decayed or have been released.

By running a full FEP analysis it may be possible for simple models to be developed that are fully justified by demonstrating that all relevant FEPs have been considered and incorporated as appropriate. These models can then be easily reviewed by regulators.

6.3 U-238 SERIES MODELLING

Mike Thorne presented.

A project workshop was held in Paris in February, hosted by EdF. There were three active participants present. It is hoped that more engagement with others outwith the initial group will occur throughout the project, much as achieved in the Ra-226 project. There is the possibility of combining the U-238 series project with future work by the radium working group.

The emphasis of the project is on deep disposal and groundwater discharge of the higher elements in the decay series. Disequilibrium within the uranium series is a key consideration for performance assessments; it is important to ascertain how disequilibrium will affect assessments, particularly in relation to differing biogeological conditions.

The top three elements of the decay chain can largely be decoupled from lower series radionuclides. Radium would however be a consideration for both aspects due to in-growth.

A number of discussions took place at the workshop, including the level of scientific understanding of data issues, for which it was noted that a synthesis of the primary literature is required. There is a large database of parameter values available (e.g. TRS 472); however the way in which data are presented is an issue – tables for individual elements are presented and it is unclear as to when values for different radionuclides for the decay series have been derived from the same literature source. It is therefore necessary to go back to the original literature to interpret the data for the repository assessment context.

Site specific data issues were also considered and it was considered that there would be benefit in building bridges with the NORM working group within EMRAS II.

Different modelling approaches need to be considered, including potentially, whether the CIEMAT Se-79 model and the Andra multi-layer model could be applied in this context and a comparison of the structure of these models may be beneficial.

The accessibility and suitability of site monitoring data is also an issue. Sites that are subject to remediation efforts are likely to hold the relevant data required. Similarly, uranium waste heaps may provide relevant data; particularly where groundwater pumping has occurred and then ceased, allowing groundwater recovery, which could be analogous to the upwelling of groundwater from a repository. These could provide the independent data sets required for model validation.

A report of the discussions at the workshop is available. This concluded that the focus of the working group should initially be on the primary literature to establish the origin of internationally recognised parameter values and the relationships between these. Consideration will then be given to the different approaches adopted in the models to determine whether or not the different models are all effectively doing the same calculations. This will lead to a greater understanding of the issues arising with current modelling approaches.

The final stage will involve a model intercomparison exercise for which a Spanish uranium site will be used to derive an assessment scenario. This site was exploited between 1955 and 1975 and was subject to remediation activities in 1999. A robust environmental sampling and characterisation campaign took place during the remediation phase. The site is largely arable agriculture with some grassland and woodland. Data have been published for the site so are readily available.

The forward work plan is therefore to start with development of an inventory of existing models. To date this includes the NDA (RWMD) and Andra models. Whether or not the CIEMAT Se-79 model can be adapted is being considered. Additional models are invited. A FEP/interaction matrix analysis will be conducted within the context of current models to determine whether or not they include all relevant processes. Scenarios will be developed on the basis of the Spanish site by the end of October, enabling any model development to occur prior to this. Quantitative model comparisons will then take place from October.

Wider participation in the project is invited.

Discussion

The benefit of going back to the original source of data was noted and recommendations made for supporting data to be collated (e.g. organic matter content of soils etc). The work of the TRS working group within EMRAS I has been very beneficial in bringing together required data, but further supporting data is required in some instances to inform performance assessment model development and application. There will be a significant effort required in going through all of the primary literature of relevance. The EMRAS database will be used in the first instance to identify the relevant literature.

6.4 SE-79 IN THE BIOSPHERE – PHASE 2

Graham Smith presented.

A version 2 proposal for further work on Se-79 was distributed in November. The focus is on soil-crop uptake. Phase I focused on FEPs and the development of an interaction matrix for selenium based on information from a range of experts on selenium environmental behaviour. The objective was to provide justification for model approaches. However, a lot of uncertainties were identified as a result of the project. Volatilisation was identified as a potentially important process that could reduce the

importance of Se-79 in biosphere modelling. However, many are nervous about relying on this process to justify excluding this radionuclide from further research efforts.

How to select parameters for assessment models under different conditions is still an issue for many. It may be possible to learn more from studies on stable selenium, such as historical studies on the addition of selenium to agricultural soils. However, the input mechanism is considerably different from the contexts being considered for performance assessments.

The objectives of the Phase II proposal are therefore to address the implications of different soil water conditions for selenium environmental transfer and to consider alternative model approaches to address this. Specific tasks included a review of selenium model assumptions under different conditions (the CIEMAT Se-79 model allows multiple soil layers to be investigated) and to investigate soil accumulation. Reactive transport methods plus other relevant models participants want to offer could also be included. IRSN has already indicated a willingness to participate in this task.

It is planned that a first stage of review will be developed through the summer and an extended project scope distributed for consideration in September. A workshop is then planned to be held in November to share experience on Se-79 modelling approaches and to review progress. Consideration will be given to when data should be included in models and what the implications are for site characterisation activities. A draft report is planned to be produced by January 2011, and finalised by the end of March.

Support has already been offered from Andra, NUMO and Posiva. Further support and participation is invited.

6.5 DETERMINATION OF EFFECTIVE KD FOR SELENIUM AND URANIUM-THORIUM-RADIUM.

Graham Smith presented on behalf of Lara Duro (Amphos21).

A proposal has recently been distributed for a project to investigate the reactive chemistry of selenium and the uranium decay series as a means of addressing problems associated with choosing Kd values for the near-surface environment. The project is based on techniques used for the deeper geosphere that have been applied in studies undertaken by Amphos21 for the SKB Forsmark site. This work was presented at the 2009 BIOPROTA workshop.

The focus of the project will be on the GBIZ, the transition zone between the deep bedrock and the surface Quaternary sediments, by considering the retention capacity of Quaternary deposits using a coupled transport model. A single Kd will be calculated for each radionuclide that takes account of retention in heterogeneous deposits.

In relation to radium, the dynamic relationship with its ancestors will need to be considered, which is a complex issue. The issue will therefore be broken down into steps. The project will consider the transfer to sediments and soils and vegetation and will look at the effective distribution coefficients

The proposal was distributed to sponsoring organisations in March. The initial proposal was focused on the uranium decay chain; however selenium could be incorporated. Feedback on the original proposal is encouraged (to lara.duro@amphos21.com) such that the project can be progressed within this BIOPROTA working year.

Discussion

It will be interesting to see whether the range of effective Kd values observed from the study are similar to those in the published literature and those generated as a result of site characterisation programmes. The approach could also be beneficial in justifying model parameter selection; however a good understanding of the site is required in order for the approach to be applied.

6.6 PARTICIPANT INTEREST AREAS: OBSERVATIONS FROM THE MEETING

A number of interest areas were identified throughout the workshop. These were discussed and provisional decisions made as to whether areas should be progressed. Results of these discussions are summarised below.

Topic	Current action	New action	Observation only
Characterisation programs and information / experience sharing	Maintain the link with EMRAS II WG3		
Stable element verses trace radionuclide data, which is better, when, why?		Can that the two approaches can be complementary? Mike Thorne agreed to develop some ideas as a basis for discussion.	
Iodine retention in lichen			See next topic
Information for cold climates			Nagra, NRPA ANDRA and other reports of potential value could be made available. Link to EMRAS WG3.
Se volatilisation and redox behaviour in soils	The Phase II Se-79 project is giving special consideration to these issues.	A proposal for an extended work programme will be developed to include testing of CIEMAT Se model and other approaches. Data for model testing are requested.	
Ra-226 and progeny	Workshop report to be finalised and distributed.		Take account of the results in the U-238 series project
Data interpretation and application of the new IAEA TRS 472 data compilation			For information, need to access underlying references
Use CR instead of TF for transfer to animals		Ideas are invited for way of refining current approaches	Use of allometric models
Detection limit for plant CR, e.g. because of soil adhesion			Ensure do not double count, although implications probably

Topic	Current action	New action	Observation only
			low. IAEA report on deposits & contributing elements by Wyttenbach may be relevant.
IAEA is developing a new guide on the Safety Case and Safety Assessment for Radioactive Waste Disposal			New guide is due to be issued of the course of the next year. A draft is available, designated DS355.
It is generally assumed that there will be no change in radio-sensitivity of humans or NHB. However there may be changes in our understanding of that sensitivity, in terms of radiation in general and in terms of the effects of individual radionuclides.		See next topic	To be noted
Closer consideration of uncertainties in dose coefficients		Mike Thorne agreed to write a note identifying issues for key radionuclides, such as I-129. Other contributions are invited.	ICRP are currently looking to update dose coefficients
Analogue approach to environmental change			EMRAS II WG3 is considering this approach
Assessment of the future dynamic evolution of a site			Complementary approach to that in topic above, also being considered in EMRAS II WG3.
Comparing Biosphere Dose Conversion Factors (BDCFs) for key radionuclides		Graham Smith agreed to write a note identifying scope and possible value. Other contributions are invited.	Simplistic results comparison may be problematic since methods of computation are very different. However, this approach may lead to early identification of the main differences in approach, which may need to be justified, or mitigated.
Tools for Knowledge Quality Assessment for the biosphere are part of the overall performance			Posiva methodology available.

Topic	Current action	New action	Observation only
assessment			
Applying the CIEMAT Se-79 model to U series, Tc-99 and other redox sensitive nuclides		To be included in proposal for extended work programme of the current U-238 series project	Further consideration of Tc-99 may be appropriate
Reactive chemistry approach to effective Kd estimation in heterogeneous media	Responses to current proposal to be sent to Lara Duro		This project will inform how to handle redox sensitive elements
Use of information on site investigation, e.g. Bayesian statistical tools to combine data distributions.		A BIOPROTA workshop on Bayesian statistics was suggested. Ideas expanding on this suggestion are invited.	
Stylised approach to human intruder dose assessment		Graham Smith agreed to develop a proposal for developing such an approach	
Transitions in biosphere conditions and potentially related acute releases across the geosphere-biosphere interface. How to identify? How to assess?			Assessed acute affects are sometimes generated as modelling artefacts, but may also be expected to arise in the real world as a result of human actions and natural change, or in combinations of both. Is modelling of change through a step transition process adequate? Are there contexts where we need to be more realistic?
Specialised database development	Participants are asked to consider the options suggested by Thomas Hjerpe.	A questionnaire on the way forward is to be developed.	
Non Human Biota dose assessment for waste repositories	Current project report to be finalised during the summer	Karen Smith agreed to update the next stage proposal concerning situations where NHB screening levels are exceeded and to provide guidance for other endpoints.	

7. FORUM ADMINISTRATIVE ISSUES

Yves Thiry provided feedback from the Sponsoring Committee meeting.

For current and on-going proposals, sponsoring organisations are requested to provide feedback and offers to support as soon as possible to allow projects to get underway. This is particularly the case for the Se-79 phase II and reactive chemistry/effective Kd proposals. It was noted that at the 2009 meeting, the idea was raised for a phase 3 project on Cl-36 to compare models against real data. Whether to progress this will be determined when data are produced from ongoing projects in this field.

For ongoing projects, it was suggested that the priority for the uranium series decay chain project should be on defining an appropriate scenario. Further development of the work programme may be required in 2011/12. This could include more robust considerations of the geosphere-biosphere interface zone and processes linked to reactive transport modelling. Further detail is to be provided on project timings associated with the C-14 project. For the BIOPROTA specialised database a questionnaire is to be developed and circulated to capture the opinions of sponsoring organisations.

Sponsoring organisations agreed that the current BIOPROTA philosophy should remain the same such that the objective is to provide a forum for the exchange of information and for collaboration. The flexibility offered by the forum approach was appreciated.

For the 2011 meeting, the opportunity to combine with the Canadian ECORAD conference was noted. Agreement would be required by NWMO and the conference organisers. An opportunity for presentation of some of the work programmes of the forum to a wider audience would be a key benefit. Alternatives to this would be Vienna (at the IAEA) or London (hosted by the NDA (RWMD)). Further consideration of these options is required.

Previously, the idea for a BIOPROTA symposium in 2012 has been raised to mark the 10th anniversary of the Forum. Andra is potentially interested in hosting the event, but there would need to be support for the idea from other sponsors to help this go ahead. A draft plan for the meeting is to be prepared by Andra and the Technical Secretariat. This will detail ideas for the main sessions that could then be sub-divided as appropriate. The meeting could be beneficial in promoting the output from the Forum and gaining intelligent input from keynote speakers on topics of particular interest.

Laura Limer was particularly thanked for her contribution to the organisation of the Cl-36 projects.

Sven Keesman (Nagra) was selected as the 2010/11 chair of the Forum.

APPENDIX A. LIST OF PARTICIPANTS

Participant	Affiliation
Andrew Sowder	EPRI, USA
Ari Ikonen	Posiva, Finland
Bjorn Soderbeck	SKB, Sweden
Danyl Perez-Sanchez	CIEMAT, Spain
Frank Garisto	NWMO, Canada
Geert Olyslaegers	SCK•CEN, Belgium
George Shaw	Nottingham University, UK
Gerhard Pröhl	IAEA, Austria
Graham Smith	GMS Abingdon, UK (BIOPROTA Technical Secretariat)
Jani Helin	Posiva, Finland
Jürgen Gerler	BfS, Germany
Karen Smith	RPS Planning & Development, UK (BIOPROTA Technical Secretariat)
Laura Limer	Quintessa, UK
Laura Marang	EDF, France
Maryla Wasiolek	Sandia National Laboratory, USA
Mike Thorne	Mike Thorne and Associates, UK
Neale Hunt	NWMO, Canada
Ryk Klos	Aleksandria Sciences, UK
Shulan Xu	SSM, Sweden
Simon Norris	NDA RWMD, UK
Sten Berglund	SKB, Sweden
Steve Sheppard	EcoMatters, Canada
Sven Keesman	NAGRA, Switzerland
Takahito Miki	JGC Corporation, Japan
Thomas Hjerpe	Saanio & Riekkola, Finland
Tobias Lindborg	SKB, Sweden
Tomoko Kato	JAEA, Japan
Ulrik Kautsky	SKB, Sweden
Yves Thiry	Andra, France