

## **BIOPROTA: An international forum for environmental modelling in support of long-term radioactive waste management**

K.L. Smith, G. Smith  
Enviros Consulting Ltd  
D5 Culham Science Centre, Abingdon, OX14 3DB  
United Kingdom

A. Laciok  
Nuclear Research Institute  
CZ-25068 REZ  
Czech Republic

### **ABSTRACT**

An international Forum, BIOPROTA, has been set up and maintained which allows common long-term environmental radiological assessment problems, such as post-closure modelling studies to be identified and then addressed. The focus of the Forum is to address key uncertainties in environmental modelling and related dose assessment with special reference to evaluation of the long-term impact of contaminant releases associated with radioactive waste management. The application of shared resources results in effective resource management and the development of common solutions to common problems.

The Forum began in 2002 and has benefited from the knowledge and experience of organisations from Belgium (SCK.CEN), Czech Republic (NRI), Canada (OPG), Finland (Posiva), France (ANDRA, EdF), Japan (NUMO), Korea (KAERI), Norway (NRPA), Spain (ENRESA, CIEMAT), Sweden (SKB, SSI), Switzerland (Nagra), UK (Nirex, Nexia, UKAEA) and the USA (EPRI). These organisations include a mixture of operators, regulators and research institutes, and hence, including the participation of their technical support organizations, constitutes a very broad-based Forum. Enviros has acted as the technical secretariat to the Forum since its formation.

Initially the Forum focused on three themes aimed at advancing knowledge and improving model predictions relating to performance and safety assessments:

- |         |                                                                                                                                                                                                                                                                                                                       |
|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Theme 1 | Development of a database to meet the key biosphere assessment information deficiencies.                                                                                                                                                                                                                              |
| Theme 2 | Implementation of a series of tasks to address key modelling issues, including uncertainties and inconsistencies in the modelling of inhalation, irrigation and soil contamination dose pathways; and approaches to the modelling the transfer of radionuclides across the geosphere-biosphere interface zone (GBIZ). |
| Theme 3 | Provision of guidance on site characterisation and experimental and monitoring protocols relevant to improving confidence in the biosphere component of the overall performance assessment.                                                                                                                           |

Substantial work under Themes 2 and 3 was completed in 2005/06 resulting in the publication of a variety of reports and guidance documents. Results of the model comparisons conducted under Theme 2 suggest that we can be confident in model structures and we have gained knowledge of the sensitive assumptions. Population of the database produced under Theme 1 is ongoing after release of an initial version which focused on data for Cl-36, Se-79, Tc-99, I-129, Np-237 and U-series radionuclides.

In 2006, BIOPROTA received further international interest. The 2006 annual workshop identified a series of current issues for which proposals for tasks aimed at addressing these issues are under development. This includes exchange of information on models and processes of relevance to Cl-36 behaviour, as well as modelling the disequilibrium in the U-238 decay chain in environmental systems; more precise understanding of released C-14 distribution within various environmental carbon pools; and studies of the GBIZ under environmental change. A special workshop was held on Cl-36 behaviour and the workshop report published.

An overview of the current state of play in biosphere modeling and dose assessment programmes relating to radioactive waste management will be presented based on national presentations by Forum members at the 2007 workshop and the key research outputs developed through the Forum will be described.

## INTRODUCTION

BIOPROTA is a collaborative research Forum, managed and supported financially by a Sponsoring Committee. The Forum was set up in 2002 to address the key uncertainties in long term assessments of contaminant releases into the environment arising from radioactive waste disposal and focuses on key radionuclides and the key biosphere migration and accumulation mechanisms relevant to those radionuclides.

At the outset, it was recognised that there are radioecological and other data and information issues which are common to specific assessments required in many countries. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and provide a transparent and traceable basis for the choices of parameter values as well as for the wider interpretation of information used in assessments.

Overall the intention of BIOPROTA is to make available the best sources of information to justify modelling assumptions made within radiological assessments constructed to support radioactive waste management. Particular emphasis is placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities.

Participation is aimed at national authorities and agencies with responsibility for achieving safe and acceptable radioactive waste management, both regulators and operators and is driven by assessment needs identified from previous and on-going assessment projects. The Forum is currently sponsored by organisations from Belgium (SCK.CEN), Czech Republic (NRI), Canada (OPG), Finland (Posiva), France (ANDRA, EdF), Japan (NUMO), Korea (KAERI), Norway (NRPA), Spain (ENRESA, CIEMAT), Sweden (SKB, SSI), Switzerland (Nagra), UK (Nirex, Nexia, UKAEA) and the USA (EPRI). Enviros has acted as the technical secretariat to the forum since its formation.

Annual workshops are held at which issues relating to radioactive waste management practices are discussed and common themes for research and collaboration identified. Such issues are addressed through additional workshops and/or task groups. Details of the achievements of the forum to date and the current and immediate future work plan are outlined below.

## ACHIEVEMENTS TO DATE

A preliminary workshop was held in June 2002 to determine which are the common key issues relating to particular radionuclides and biosphere processes. Some of the issues identified were of narrow interest, whereas others were found to be relevant to several of the participating organizations [Ref 1]. These

common issues provided the basis for a provisional work programme that was structured under a series of Themes and Task Groups<sup>1</sup>.

#### **Theme 1: Development of a database for key radionuclides and process data**

The overall objective of Theme 1 is to provide data and supporting information relating to key Features, Events and Processes (FEPs) and the behaviour of key radionuclides in the biosphere in the form of a database to meet the key biosphere assessment information deficiencies. Radionuclides included Cl-36, Tc-99, Se-79, I-129, Pb-210, Po-210, Ra-226, Th-230, Np-237, U-238 and Pu-239. Version 2.0 of the database was released in November 2006 (Refs 2, 3). The task of populating the database is ongoing due to the substantial number of parameters for which data are required and because the key radionuclides and parameters vary from time to time as new sites and disposals are considered along with alternative near field and geosphere transport assumptions, leading to differently significant releases to the biosphere which have to be considered.

#### **Theme 2: Model testing and development tasks**

Theme 2 investigated the mathematical and conceptual modelling assumptions of key biosphere processes. There were six tasks under Theme 2.

##### *Task 1 – Irrigation.*

The objective of the irrigation task was to investigate the calculation of doses arising from interception of contaminated irrigation water by growing crops and the consequent contamination of the food consumed by humans. The intention was to compare assessment models for this important exposure pathway and hence:

- improve confidence in the treatment of the relevant processes and data assumptions;
- identify the circumstances in which different processes are important, hence requiring different modelling treatment; and,
- identify where important data may be lacking.

Methods for modelling irrigation varied between participants, but predictions were within a factor of 10 of each other [Ref. 4]. The main reasons for discrepancies in results are associated with the treatment of weathering and translocation, post deposition. Values for translocation varied considerably between the participants and there were different interpretations of weathering and translocation data. These differences arise in part because of the different irrigation practices used in different areas, which are largely climate driven.

##### *Task 2 – Inhalation.*

The inhalation task involved the calculation of doses arising from inhalation of particles suspended from soils within which long-lived radionuclides, particularly alpha emitters, had accumulated. As with Task 1, the intention was to:

- improve confidence in the treatment of the relevant processes and data assumptions;
- identify the circumstances in which different processes are important, hence requiring different modelling treatment; and,

---

<sup>1</sup> Reports for each of the tasks conducted within BIOPROTA can be obtained from the Forum website [www.bioprotacom](http://www.bioprotacom).

- identify where important data may be lacking.

Variability in model predictions arose to some extent because of the different treatments of processes in the models, but mainly because of different parameter value assumptions [Ref. 5]. Differences in model results were found to relate significantly to:

- the degree to which human disturbance results in high dust levels;
- the degree of enrichment in radionuclide content of the resuspended dust; and,
- the occupancy period for which high dust levels were assumed to persist.

For highly particle-reactive radionuclides reaching the soil in irrigation waters, where re-suspension has the potential to be the most important pathway of exposure, the approach to modelling radionuclide retention in soil had little impact on the results obtained. This arose since such radionuclides are retained in top soil for long periods, but are relatively rapidly redistributed through it by processes such as ploughing and bioturbation.

*Task 3 - Model review and comparison for C-14 dose assessment.*

The objective of Task 3 was to review and discuss modelling of the transport and fate of C-14 and account for the treatment of C-14 processes, pathways and accumulation in the biosphere [Ref. 6]. Particular attention was given to the appropriate choice between dynamic and equilibrium assessment models. The Task involved a review of documents detailing ecosystem models of C-14 developed or applied in the context of nuclear waste management. From the review conducted, a range of issues and data gaps were identified. As such, C-14 modelling is the subject of further consideration within the forum.

*Task 4 - Model comparison for long term accumulation in soils.*

Task 4 involved a model intercomparison focused on the long-term accumulation of long lived radionuclides in soils. Two often used scenarios were adapted as means of contamination, the well scenario, where contaminated well water is used for irrigation of agricultural land and a river scenario, where contaminated river water floods the agricultural land. The main tasks of the exercise were to test the significance of alternative treatments, and to identify weaknesses in data required to deal sufficiently with the relevant processes [Ref. 7].

For the well scenario, radionuclide concentrations in soil were calculated with reasonable agreement. Differences in model predictions arose due to:

- the inclusion of cropping processes by some modellers, which decreased the radionuclide concentration in the soil for those radionuclides with high soil to plant transfer coefficient such as Cl-36, Se-79 and Tc-99.
- the application of different modelling approaches for percolation loss. The impact of this was largest for assumed low Kd radionuclides such as Tc-99.
- lower irrigation rates as depicted by some participants, which reduced soil activity concentrations.
- the consideration of a sub-surface soil compartment. This served to either reduce the upper soil compartment concentration (radionuclides are mixed into a larger soil section) or increase it by transferring radionuclide back via capillary rise, depending on other assumptions for water movement.

For the river scenario, 3 organisations participated. Comparable results were obtained with the exception of the low Kd radionuclide Tc-99 due to differences in percolation model assumptions.

*Task 5 – Analogues*

Analogue information can increase our conceptual understanding of long term repository behaviour and behaviour of radionuclides in the environment in support of post closure performance assessments (PA). They can also provide quantitative data for PA models and are a communication method to pass on information to a non-specialist audience. The analogues task was aimed at promoting considered application of analogues in future safety assessments and public communication.

A review of past and present use and understanding of natural analogues relating to biotically-influenced biosphere processes was conducted. The review was limited in scope [Ref. 8] and, in the nature of the BIOPROTA forum, was intended primarily to provide a basis for discussion and to act as a pointer for what further work could be useful at the site specific level.

*Theme 2: Task 7 – Geosphere-Biosphere Interface Zone (GBIZ)*

Historically, Performance Assessments (PAs) simulating the evolution of geological repositories for radioactive waste have considered the repository system in three basic parts, namely the near-field, the far-field (or geosphere) and the biosphere. The flux of radionuclides assessed to leave the domain of the geosphere model is often assumed to discharge directly into a part of the biosphere, such as soil or a surface water body, with little explicit consideration of the processes involved. In reality, the transfer of radionuclides across this geosphere-biosphere interface (GBI) could be very complex, involving numerous inter-linked physical, chemical and biological processes that often occur in cyclical or episodic ways [Ref. 9].

The objective of the GBIZ task was therefore to support better account of the treatment of radionuclide transfer through the geosphere-biosphere interface zone, and the related accumulation/dispersion/dilution processes which should be considered in order to provide appropriate confidence in PA results.

Following review of approaches, it was recognized that assessment models should be kept as simple as possible, consistent with the objectives of the assessment. Nonetheless, there is a wider need to demonstrate a good understanding of the system under assessment. This can involve a relatively detailed consideration of the issues, going beyond the immediate requirement of assessment models.

Further consideration is being given to the treatment of the GBIZ within the Forum.

**Theme 3: Site characterisation, experiments and monitoring.**

Biosphere description embraces many disciplines generating data that have to be identified, described, measured and integrated in order to construct a descriptive ecosystem model that identifies and quantifies biotic and abiotic patterns and processes of importance for the ecosystem on a site. The objective of Theme 3 was therefore to provide advice about the biosphere features of a site which it may be useful to determine because they are especially relevant to the evaluation of radiation exposures over the long term.

A review of the basis for biosphere characterisation was undertaken [Ref. 10], focusing solely on the requirements of a long-term PA, noting the progression from reliance on generic or regional data to the need to derive and use site-specific data as repository development progresses.

## **CURRENT AND FUTURE WORK PROGRAMME**

Following the successful completion of the three initial themes, the Forum has identified new research priorities, some of which were initiated in 2005-06. A brief description of each task is outlined below.

### **International forum on chlorine-36 in the biosphere**

Cl-36 is an important contributor to potential radiation doses in the long term, arising from release into the biosphere from radioactive waste disposal facilities. Previous work has suggested that the main exposure pathways are ingestion of drinking water, milk and milk products, meat and vegetables and grain products. However, the data necessary for radiological assessment are scarce. The objectives of the forum were:

- to provide an open forum for presentation and discussion of environmental processes involved in Cl-36 migration and accumulation in the biosphere and on how to model such processes; and,
- to develop recommendations for the direction of continuing research as input to long-term radiological assessment.

A lot of information was exchanged among participants with different backgrounds and technical contributions to make to waste disposal safety assessment. Cl-36 was found to be significant in terms of being a major contributor to dose for both deep and shallow disposal facilities for different kinds of wastes (Ref 11). Several common themes and issues arose during the workshop and these are currently being discussed with a view to initiating further assessment work on Cl-36 within the Forum, to test the significance of alternative model assumptions concerned with the dynamics of water movement during the growing season and the recent history of nutrient uptake.

### **In situ study of the long term sorption of iodine onto organic matter**

Iodine is generally present in environments as an anion (either iodide or iodate) and is therefore soluble in groundwater and migrates relatively quickly through rock and overburden to low-lying landscape positions such as wetlands where it can be retained by the organic matter of soils (iodine can only be retained in its oxidised form). Peat bogs are often located at low-lying landscape positions and are very rich in organic matter and therefore iodine is likely to “accumulate” in peat bogs.

An 18 month experimental study has therefore been initiated, which aims to increase understanding of the mechanisms that govern the mobility and transport of iodine in peat bogs, and to acquire values for assessment models such as soil Kd and plant CR (concentration ratio). The study is focusing on:

- the biogeochemical cycle of iodine in the peat bog including:
  - the transfer of iodine along the carbon cycle in the peat bog (plant uptake, speciation of iodine in the plant, consequences of the biodegradation of the plant material on the availability of iodine in the peat); and,
  - the role of the redox potential on the migration and the speciation of iodine in the peat bog.
- the retention of iodine onto the peat; and
- the relation between the chemistry of organic matter and the retention of iodine.

Such an understanding of the mechanisms that govern the fate of iodine in peat bogs will form the basis for a better model of the transfers of this element in these types of ecosystems. The study is due to conclude in 2007.

### **Evaluation of codes for geosphere and biosphere compartmental contaminant transfer modelling**

One of the goals of BIOPROTA is the search for opportunities of synergies. A workshop was therefore held on the inter-comparison of codes and their flexibilities for model development and implementation. The current wealth of models and codes is a sign of healthy independent development by various agencies. Most agencies are moving away from hard coded models, since they allow for little model flexibility, requiring the user to modify the source code in order to adapt the model. By comparing codes, illustrating their capacities, giving examples of their strengths and weaknesses it was could enhance code refinement and help point towards future development. The workshop provided a platform for knowledge exchange on various codes and set the stage for synergy exploitation in the fields of code, model and data base development.

### **Application of the latest guidance on protection of the environment from radiation and impacts on non-human biota to the assessment of long-term releases of long-lived radionuclides**

In recent years a number of assessment methodologies have been (or are currently being) developed to enable the impact of radioactive substances on the environment to be assessed through the calculation of dose to non-human biota. However such methodologies, and associated application guidance, have generally been developed in consideration of routine operational discharges from industrial sites where data on environmental discharges and/or environmental concentrations may be available or can be predicted with reasonable levels of certainty. In the case of releases from radioactive waste management facilities, long-term prospective assessments are required that may involve a greater degree of uncertainty and probabilistic analysis. No international consensus on the application of latest guidance and methodologies for assessing impacts on non-human biota from waste management facilities is currently available.

A workshop was therefore organised to provide a platform for open discussion on the issues associated in the application of current guidance and methodologies in Performance Assessments for long-term waste management facilities. This drew on experience in the practical application of the guidance and available approaches and provided feedback to the developers and users on methodology implementation issues.

The Forum took place in Finland on 31 January-1 February 2007, hosted by Posiva, and the workshop report is available [Ref 12].

## **FUTURE WORK PROGRAMME**

In addition to the current work programme, a number of additional tasks are under development. These include:

- Development of a conceptual model (or models) for the transport of U-238 and its progeny in the biosphere.
- Modelling of C-14 in the biosphere.
- Identification of the dominant dose pathways for key radionuclides (direct food-chain contamination from irrigation, or food-chain contamination, inhalation or external irradiation after build-up in soil), which largely builds upon Theme 2 tasks detailed above.
- Modelling of Cl-36 in the biosphere.
- Historical discharges and environmental monitoring data. This task is designed to investigate the value of historical monitoring and concurrent environmental data associated with effluent discharges to a lake, a river estuary, and a tidal area. The objective would be to assess whether

such data can provide a broad level of understanding and holistic information on the migration and fate of radioactivity in aquatic environments that could aide understanding of processes pertinent to post-closure safety assessment modelling.

## FURTHER DETAILS AND MEMBERSHIP

Further information on BIOPROTA is available on the forum website [www.bioprotacom](http://www.bioprotacom).

As noted above, the Forum is open to national authorities and agencies with responsibility for achieving safe and acceptable radioactive waste management. Anyone interested in participating in the forum should contact the BIOPROTA Technical Secretariat at [Karen.Smith@enviros.com](mailto:Karen.Smith@enviros.com).

## REFERENCES

1. Leclerc-Cessac E. and Smith G. M. (2003). *BIOPROTA: International Collaboration on Key Technical Issues in Biosphere Aspects of Long-Term Radiological Assessment*. International HLW management Conference, Las Vegas, American Nuclear Society, 2003.
2. BIOPROTA (2004). *Theme 1: Specialised Database, version 1.1*. A database prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. September 2004.
3. BIOPROTA (2006). *Theme 1: Specialised Database, version 2.0*. A database prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. November 2006.
4. BIOPROTA (2005). *Model Review and Comparison for Spray Irrigation Pathway*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: U Bergstrom (Task Leader), A Albrecht, B Kanyar, G Smith, M C Thorne, H Yoshida and M Wasiolek. Published on behalf of the BIOPROTA Steering Committee by SKB (Swedish Nuclear Fuel and Waste Management Co., Svensk Kärnbränslehantering AB), Stockholm, Sweden.
5. BIOPROTA (2005). *Modelling the Inhalation Exposure Pathway*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: M Wasiolek (Task Leader), A Agüero, A Albrecht, U Bergström, H Grogan, G M Smith, M C Thorne, M Willans and H Yoshida. Published on behalf of the BIOPROTA Steering Committee by BNFL (Nexia Solutions Ltd), UK.
6. BIOPROTA (2005). *Model review and comparison for C-14 dose assessment*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: S Sheppard (Task Leader) and M C Thorne. Published on behalf of the BIOPROTA Steering Committee by UK Nirex Ltd, UK.
7. BIOPROTA (2005). *Model Intercomparison with focus on accumulation in soil*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: A Albrecht, C Damois, E Kerrigan, R Klos, G Smith, M Thorne, M Willans and H Yoshida. Published on behalf of the BIOPROTA Steering Committee by ANDRA (Agence nationale pour la gestion des déchets radioactifs), Châtenay-Malabry, France.

8. BIOPROTA (2005). *Application of Biotic Analogue Data*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: E Kerrigan (Task Leader), G Smith, M C Thorne. Published on behalf of the BIOPROTA Steering Committee by United Kingdom Nirex Ltd, Oxfordshire.
9. BIOPROTA (2005). *Modelling Processes in the Geosphere Biosphere Interface Zone*. A report prepared within the international collaborative project BIOPROTA: Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management. Main Contributors: P Pinedo and G Smith (Task Leaders), A Agüero, A Albrecht, A Bath, H Benhabderrahmane, F van Dorp, U Kautsky, R Klos, A Laciok, T Milodowski, J-O Selroos, I Simón, D Texier, M Thorne, and M Willans. Published on behalf of the BIOPROTA Steering Committee by CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas), Madrid.
10. BIOPROTA (2006). *Guidance on Site-specific Biosphere Characterisation and Experimental Research and Field Research Protocols*. Main Contributors: E Leclerc-Cessac, M Thorne and G Thomson. Published on behalf of the BIOPROTA Steering Committee by Agence Nationale pour la Gestion des Déchets Radioactifs, ANDRA, Châtenay-Malabry, France.
11. BIOPROTA (2006). *Report of an International Forum on Cl-36 in the Biosphere*, 27-28 September 2006, Châtenay-Malabry, France.
12. BIOPROTA (2007). *Report of an International Forum on Assessment of Impacts on Non-Human Biota from Long-term Releases of Long-lived Radionuclides*, 31 January – 1 February 2007, Finland.