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BIOPROTA: INTERNATIONAL COLLABORATION ON KEY TECHNICAL ISSUES IN BIOSPHERE ASPECTS OF LONG-TERM RADIOLOGICAL ASSESSMENT

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ABSTRACT

BIOPROTA is an international collaborative project which was set up to address key uncertainties in biosphere aspects of assessment of the long-term impact of contaminant releases associated with radioactive waste management. The project began in 2002 and has benefited from the knowledge and experience of organisations from Canada, Finland, France, Japan, Russia, Spain, Sweden, UK and the USA. This paper describes the BIOPROTA objectives and scope, the on-going work programme and methods of work.

I. INTRODUCTION

The BIOPROTA project began in 2002 with financial support from ANDRA, France; BNFL UK, ENRESA, Spain; Nirex, UK; NUMO, Japan; Posiva Oy, Finland; SKB, Sweden and UKAEA, UK, to address radioecological and other data and information issues which are common to the safety assessments required in many countries. Other organisations participated through in kind support. BIOPROTA seeks to address the key biosphere uncertainties in long-term assessments of contaminant releases into the environment arising from radioactive waste disposal, associated with key radionuclides and parameters [1].

Assessments of the impacts of releases of radioactivity into the surface environment, or biosphere, as a consequence of disposal of solid radioactive waste in geological repositories, rely on a great variety of factors. Important among these is an adequate and justified level of understanding of radionuclide behaviour in the environment; particularly, the associated migration and accumulation among and within specific environmental media, and the resultant consequences for the environment and human health.

Assessment methods have been developed over several decades based on knowledge of the nature of near-surface environments and the ecosystems involved, as well as the monitoring of previous radionuclide releases to the environment, laboratory experiments and other research. It is recognised that in some cases data for assessments are sparse. Particular difficulties arise in the case of long-lived radionuclides, because of the difficulty of setting up relatively long-term monitoring and experimental programmes, and because the biosphere systems themselves will change during the period before

release to the environment and during the period of any actual radionuclide release. Such changes might arise due to natural processes and due to potential interference by mankind.

It is also the case that, for one reason or another, much radioecological research has focussed on relatively few radionuclides, e.g. Sr-90 and Cs-137. While this research has been relevant, other radionuclides tend to dominate long-term impacts that may arise from releases from solid radioactive waste repositories. Examples include C-14, Cl-36, Se-79, Tc-99, I-129, Ra-226, Np-237 and others for which relevant understanding and data for long-term behaviour are not so readily available. This is obvious from the results of many previous performance assessments for shallow and deep solid radioactive waste repositories.

The International Atomic Energy Agency's BIOMASS Project, completed in 2001, provided a basis for identifying, justifying and describing biosphere systems and the related assessment assumption for the purpose of long-term radiological assessment [2]. A methodology for the development of conceptual and mathematical models has been set out and a protocol developed for the application of data to these models. A series of Example Reference Biospheres were developed and presented, to demonstrate the procedure and to provide general points of reference for the types of models for calculation of, and the likely level of, annual individual doses per unit activity release rate into the biosphere for a variety of different geosphere-biosphere interfaces at an inland site in a constant temperate climate. The procedure illustrated could be used to develop Assessment Biospheres at specific sites.

The BIOMASS Project did not, however, address the major uncertainties arising from weaknesses in the information base. Review of input from many relevant agencies and organisations within the international collaboration project BIOPROTA during 2002 suggested that the number of important radionuclides and processes associated with migration and accumulation in the biosphere, and the number of important related radiation exposure pathways, is relatively small. Importance here is taken to mean that the identified exposures dominate in the overall performance assessment results and that significant uncertainties remain associated within the biosphere component of those assessed doses.

Arising from the identification of important uncertainties for particular radionuclides and processes, the BIOPROTA project agreed on a programme of work under three Themes:

- Development of a specialised database to meet the key biosphere assessment information deficiencies;
- Implementation of a series of tasks to address key modelling issues;
- Provision of guidance on site characterisation and experimental and monitoring protocols relevant to improving confidence in the biosphere component of the overall performance assessment.

In combination, the output of the three Themes is intended to support decisions on the next steps in site investigation and characterisation, as progress is made from site generic to site-specific investigation of repository safety assessment:

II. OBJECTIVES

The overall intention of BIOPROTA is to make available the best sources of information to justify modelling assumptions made within radiological assessments of 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.

The project 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. The objectives for BIOPROTA are:

- To provide a forum for exchange of information to support resolution of key issues in biosphere aspects of assessments of the long-term impact of contaminant releases associated with radioactive waste management;
- To make available the best sources of information to justify modelling assumptions made within radiological assessments of radioactive waste management;
- To apply common effort to finding solutions to common assessment needs identified from previous and on-going assessment projects;
- To consider the modelling assumptions of various Features, Events and Processes (FEPs) of the systems under investigation, the mathematical representation of those FEPs and the choice of parameter values to adopt within those mathematical representations;
- To provide results that are either relatively precise suggestions on what data to apply to particular assessment situations and to advise on the more generic types of information which should be taken into account when making modelling assumptions.

III. WORK PROGRAMME

During an initial workshop, the key radionuclides and processes and a method of work were identified, resulting in a work programme for the first two years of BIOPROTA. Leclerc & Smith, 2003 [1], provides details of the early development of the programme. Key issues were divided into Themes and Tasks, which were led by a Task Group Leader (TGL) from an organisation with particular interest in that topic. The Themes and Tasks were:

Theme 1: Specialised Database

Theme2: Model Testing and Inter-comparison Exercises

Task 1: Irrigation Modelling
Task 2: Inhalation Modelling
Task 3: C-14 Modelling
Task 4: Model Inter-comparison
Task 5: Biotic Natural Analogues
Task 6/7: Environmental Change and the Geosphere- Biosphere Interface Zone

Theme 3: Site Investigation, Experiments and Monitoring

Task 1: Site Characterisation
Task 2: Research Protocols

For Theme 1, the Specialised Database, the aim was to create a database for key combinations of FEPs and radionuclides which lead to more significant doses in assessments. Work included specification of the data required, design and construction of the database, setting the context and the range of applicability, population the database (primarily with data for Cl-36, Tc-99, I-129 and Np-237) and development of suggestions for revised models (in light of data quality and/or further experimental and/or monitoring work) or proposals for more extensive population of the database.

Within Theme Two, to compare models, Tasks 1, 2 and 4 were organised so that different organisations would run their specified models based on a standard assessment context and description, ensuring that only the key parameters of interest would influence the results. Either concentration in crop or soil, or dose to humans was the end point of concern. Task 1 is to evaluate the process of direct uptake into the food chain as a result of interception by crops of irrigation water contaminated with Cl-36, Se-79, Tc-99, I-129 and Np-237; in particular, the processes of interception, weathering, translocation into and within plant tissues and the effects of seasonality are of interest. Task 2 is to evaluate the assessment of doses via inhalation of dust as a result of accumulation of long-lived alpha emitting radionuclides in soil. Task 4 addresses the long-term accumulation of radionuclides in soil and their uptake into the food-chain, having been deposited from above due to irrigation or flooding over a long continuous period. The intention is that the comparison of assessment models for this important exposure pathway will:

- 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.

Task 3 involved review of modelling of C-14 behaviour in soil and uptake into crops. Task 5 involved reviewing biotic natural analogues, and determining when analogue information is appropriate to make the best use of information on the behaviour of radionuclides. The objective of this task is similar to that of work package 4 in the EC 5th Framework Project NaNet, reviewing abiotic natural analogues (www.enviros.com/zztop/nanet/nanetmain.htm). During the first year of BIOPROTA Task 6 and 7 were merged and the aim was to provide guidance on modelling transfer of contaminants across the geosphere-biosphere interface zone (GBIZ).

The two Theme 3 Tasks were also merged during the initial stages of the project, to provide guidance on biosphere site specific characterisation, detailing how to identify the types of measurements to be made, why they are useful and includes protocols of how they should be made. The Tasks are described in more detail below.

IV. Theme 1

The overall objective of the Specialised Database is to provide information relating to key combinations of FEPs and radionuclides which lead to more significant doses in assessments. The specific objectives of the database are to:

- Provide information in a database on values of parameters related to radionuclide behaviour in various environmental conditions;
- Provide guidance on how to select particular values for use in assessment calculations;
- Identify important gaps in knowledge, as becomes apparent as we try to populate the database.

It is necessary to record the parameter values, ranges and distributions used, and how the data were derived, e.g. from literature reviews or detailed model calculations. It is also important to maintain quality control on the data by maintaining a suitable audit trail to show how each item was originally generated and subsequently updated. Taking this into account, United Kingdom Nirex Limited (Nirex) offered their flexible database system, the Biosphere Databook, for use in developing a specialised database for the BIOPROTA project. The most recent version of the database (BIOPROTAv2.0: Specialised Database, September 2004) is available on CD and can be installed to operate in stand-alone mode under Windows. It incorporates an Access database and is compatible with a variety of Microsoft applications.

In BIOPROTAv2.0, some consideration has been given to the structure of the database required for recording relevant data, but relatively few data relating to key radionuclides of interest have been included. Work is continuing (detailed below) to obtain appropriate data for an updated version of the database.

V. Theme 2

Within Theme 2, several Tasks have been implemented to allow comparison and improvement of models for some key processes in relation to specific radionuclides, in accordance with the priorities already identified.

V.A. Task 1: Modelling Irrigation

As mentioned above, the aim of this Task was to identify the important processes that affect the concentration of radionuclides that accumulate in crops as a result of irrigation. There are three main ways to model interception of irrigation water:

- Using estimates from wet deposition, described by an interception factor;
- A process-oriented method, assuming a water layer retained on the surfaces of vegetation, or
- Regression of data obtained from an experimental study.

Each method has its advantages; the so called wet deposition model demands few parameter values. It may however lead to high estimates of surface contamination if consensus is not achieved concerning annual and daily irrigation rates. The film method is more process-oriented and flexible. It can be used by simple choice of parameter values to simulate plants in various stages of growth. It can also produce more plant-specific results and it is easy to keep control over irrigation volumes. However, time dependency was not taken into account in the example calculations of this Task.

Though the methods vary, most results of concentrations realised by the various models are within a factor of ten. This is in many cases due to compensating effects. For example, high initial retention is considerably reduced when weathering and translocation are considered. The main reason for discrepancies in the results is due to variability in the values used when describing processes like weathering and translocation. Surface contamination is important from a dose point of view for some radionuclides. The importance of the contamination process varies and reflects the properties of the elements involved. It is highest for elements which have a low uptake from soil.

V.B. Task 2: Inhalation Modelling

The Task involved an intercomparison of calculation methods for doses arising from inhalation of particles suspended from soils within which long-lived radionuclides, particularly alpha emitters, have accumulated.

The task did not consider inhalation of radon and radon daughters released from soils etc, other radioactive gases, nor aerosols generated from soils or water surfaces. The BIOPROTA report does consider the influence of dust loading, resuspension factors, enhancement factors, particle size and breathing rate on the dose received via this pathway.

Some observations made during the inhalation model comparison are that ploughing and wind erosion are the primary factors that result in suspension of dust from top soil, although some organisations did include others. Most but not all organisations use a dust loading approach, but others do model using resuspension factors. Occupancy and breathing rates depend on the environment and the activity that is being represented, this also relates to the dust level considered, which is usually split into low and high. Atmospheric activity concentration is typically 1E-7 at normal/low dust loading and 5E-6 for high. Soil factors play an important role in the resuspension ability of contaminants, for example, soil structure, water content, grain density, soil type, soil depth and the time period between irrigation and ploughing.

V.C. Task 3: Carbon-14

This task considered how to model the transport and fate of C-14 and account for the treatment of relevant processes, pathways and accumulation in the biosphere, including equilibration times between the newly arriving C-14 and stable C (C-13 and C-12) of the biosphere and its component systems/compartments. The Task involved a review of documents detailing C-14 ecosystem models of C-14 from nuclear waste management.

The main issue surrounding the conceptual model for C-14, from the perspective of waste management, is *When and where can mixing and isotopic equilibrium be assumed, and when and where can it not?* This must be resolved with a full understanding of the system to be modelled and carefully specified in the conceptual model and scenario.

Another issue is the definition of the temporal scale for the assessment, and in conjunction with the timescale, decisions as to whether kinetic models are useful and/or necessary.

In addition, there is still a need to understand the implications of fractionation of C-13, C-14 with respect to C-12 in the biosphere physical compartments and in the various trophic levels of both the aquatic and terrestrial systems.

Knowledge gaps do remain, the most significant of which are:

- More data required for gaseous exchange from surface water and soils to the atmosphere and how this affects the specific activity (SA) in the water and soil compartments;
- Concentration of C-14 in animal tissue with time, what is the turnover rate that determines the change in SA?
- More knowledge of stable isotope concentrations in well and groundwater would enhance the prediction capabilities using simple SA models.

V.D. Task 4: Accumulation on soils

The focus of this Task was on the long-term accumulation of the key radionuclides in soils. Two common scenarios were adapted as means of contamination; a scenario where contaminated well water is used for irrigation of agricultural land, and contaminated river water that floods the agricultural land.

An intercomparison exercise was undertaken of various models used in performance assessments to test the significance of alternative treatments and to identify weaknesses in data required to deal sufficiently with the relevant processes. The exercise allowed users to evaluate the functionalities of their codes and judge how effectively their codes handle data input, element- and site specific parameterisation, calculation and output specification in comparison with other codes and models.

For the scenario using contaminated well water for irrigation, eight organizations participated and calculated radionuclide concentrations in soil with reasonable agreement, and explainable exceptions. Three organizations participated in a calculation for a river flooding scenario. They obtained compatible results except for the low Kd radionuclide Tc-99 for which differences in percolation modelling became apparent. A number of observations can be made:

- Cropping processes were modelled by some but not all. This 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.
- Slightly different modelling approaches for percolation loss were applied. This impact was largest for low Kd radionuclides such as Tc-99.
- Lower irrigation rates (as depicted by some participants) reduces soil concentrations and related overall doses.
- Modelling of seasonal change generally reduces soil concentrations. The difference between summer and winter is most significant for Tc-99 (more than factor of 2).
- Consideration of a lower soil compartment can either reduce the upper soil compartment concentration (Radionuclide mixed into a larger soil section) or increase it by transferring radionuclide back via capillary rise.
- Differences of the calculated total doses are, in most cases, explained by differences in the associated soil concentration.
- The ratio of radionuclide concentrations in the soil between the well and river scenarios shows good agreement to the analytically estimated value of 0.005.

V.E. Task 5: Biotic Natural Analogues

Analogues can play many roles within a radiological assessment. They have many advantages as a data source, however, good analogues are rare and they often require careful interpretation.

This BIOPROTA Task focussed on analogues that are biotically influenced in the near-surface. The analogues of interest are those related to key radionuclides located in a terrestrial environment that is broadly comparable to one of the environments where a repository may be sited. The key radionuclides of interest were C-14, Cl-36, Se-79, Tc-99, I-129, Np-237, and the U-238 series. The key parameters of significance to this study were K_d, root uptake factors, plant concentration factors, animal transfer factors and crop interception. If no relevant analogues exist for the relevant radionuclides, there may be an interest in other radionuclides or elements, whose behaviour is thought to be similar in those relevant environments.

The aim of the Task has been to identify the qualitative and quantitative information derived from studies that might be considered to relate to biotic analogues and to make recommendations for how this information may be used in future performance assessments.

Based on recent project specific assessments, updated advice would be useful to focus future efforts on those processes and data which are both important and relatively poorly understood, as these are potential targets for future analogue studies.

V.F. Task 7: Geosphere-Biosphere Interface Zone (GBIZ)

Performance Assessments simulating the evolution of geological repositories for radioactive wastes consider the repository system in three basic parts, namely the near-field, the far-field (or geosphere) and the biosphere. This tripartite arrangement is often reflected in the assessment codes used to evaluate the transport behaviour of radionuclides released from the waste.

Conceptual and mathematical models of the transfer of radionuclides from the geosphere to the biosphere underpin the assessment codes, but they often represent transfers in a very simplistic manner. Sometimes it is represented by little more than an assumed advective discharge of contaminated water from deep rock into near-surface aquifers or to overlying unsaturated media such as sub-soils and soils, or directly into surface water bodies, without any indication of a real extent of the release. In reality, however, the transfer of radionuclides from the geosphere to the biosphere can be much more complex; involving numerous inter-linked physical, chemical and biological processes that often occur in cyclical or episodic ways. Generally, such processes lead to dilution of the radionuclide concentration in the groundwater, though the degree of dilution depends on the spatial details. In certain circumstances, some of these processes have the potential to re-concentrate radionuclides at or near the surface, and thus might cause larger exposures of people than would otherwise be expected.

The objective of this Task was to be able to account for the treatment of the GBI zone, and the related accumulation/dispersion/dilution processes which have to be explored to help in the completion and the confidence of "safety assessment scenarios" on this important issue. The Task Group considered present assessment assumptions for:

- How source term/s from the geosphere to the biosphere are represented in their corresponding assessments;
- The main geosphere transport processes and the geosphere boundary conditions;
- The hypotheses assumed for biosphere analyses, such as: type of source term/s assumed or calculated to the biosphere, the biosphere media or processes through which radionuclides reach biosphere components.

VI. Theme 3

Biosphere description is a multidisciplinary endeavour that embraces many factors which have to be identified, measured and integrated in order to construct appropriate ecosystem models that describe and quantify biotic and abiotic patterns and processes of importance for the potential migration of radionuclides and the future evolution of a site. Biosphere descriptions can be used as baseline models for devising monitoring programs to detect short-term disturbances caused by repository development or for comparison with model simulations to determine more long-term effects or changes caused by the repository. Biosphere research at a site can also be used to support data collection and interpretation for use in environmental assessments. Furthermore, biosphere descriptions can serve as analogues for future conditions.

Considering the above, Theme 3 of BIOPROTA has two broad objectives. Under Task 1, the objective is to develop guidance on biosphere site-specific characterization. Within this Task, the intention is to identify the types of measurements to be made, describe why they are useful and set out the protocols of how they should be performed. However, it was recognized that biosphere site characterization and underlying research both contribute to the needs of post-closure radiological performance assessment and that it would, therefore, be appropriate also to address protocols for research intended to support long-term biosphere assessments.

The aim of the task was to produce guidance on biosphere site specific characterisation for long term radio logical Performance Assessments and develop protocols for the design of research intended to support long-term biosphere performance assessments. The intention was to:

- Develop a list of parameters that are key to long-term performance assessments; taking into account information and analyses arising from other tasks within BIOPROTA and elsewhere;
- Understand what factors affect the representative nature (or otherwise) of the measured parameters, e.g. by taking spatial and temporal variability into account;
- Identify what type of measurements should be made in order to determine values of the key parameters;
- Identify whether the required measurements should be made as part of an active site characterization programme, as a component of passive monitoring or as an integral part of experimental programmes of research.;
- Review the protocols that are currently available for making these types of measurements;
- Comment on the ranges of applicability of the available protocols;

- Identify deficiencies in available protocols, e.g. in terms of their ranges of applicability and in respect of their effectiveness in determining values of the quantities of interest;
- Make recommendations as to what protocols are likely to be most appropriate in different circumstances, and on types of measurements for which enhancements of existing protocols or new protocols are required.

The above was to be achieved by compiling information on existing approaches to site characterization and protocols for experimental research, site characterization and monitoring. From this compilation and review activity, the intention is to both identify current best practice and to determine areas for which approaches need to be refined or extended, and for which new protocols need to be developed.

The report considers how modellers characterise sites now, and how this relates to conditions expected in the far future. The applicability and deficiencies of the available protocols e.g. in terms of their range of applicability and in respect of their effectiveness in determining values of the quantities of interest. The aim is for this to support the development of site specific characterisation guidance to support long term performance assessment.

VII. Collaboration

There are many links between BIOPROTA and other international fora, not least the International Union of Radioecology. The BIOPROTA sponsoring organisations provided funding to the IUR to support the work of the task force investigating waste and radioecology. Several workshops were held, which included participants with detailed knowledge of both programmes, and a report of the findings will be published shortly. Further information is available from the IUR website (www.iur-uir.org).

In addition to BIOPROTA and IUR activities, as part of the IAEA Programme on Environmental Modelling for Radiation Safety (EMRAS), the IAEA have convened a working group for the revision of the Technical Reports Series No. 364 "Handbook of parameters values for the prediction of radionuclide transfer in temperate environments" [3]. In order to update the report, the working group are conducting an initial analysis of the existing data. In addition, the scope is to be extended to consider additional compartments and processes. It is also necessary to consider the availability of data for new environmental conditions, such as under cold and tropical climates, or concerning inhabited environments [4].

VIII. Future Work

It is recognised that the Specialised Database can be an extremely useful tool for assessment purposes, and therefore there is continued support for its development. During 2005, there will be a project to critically research the literature containing information on the behaviour of key radionuclides that could be of use in biosphere modelling to support radiological performance assessments. The information derived from the research will be used to populate the BIOPROTA Specialised Database. Data entered onto the database will be accompanied by relevant supporting information to indicate its provenance and any other notes that might impact on its future use.

The GBIZ also retains interest for a continuing project in the future, within the BIOPROTA Framework. The objective would be to reduce uncertainties and/or

conservative assumptions in assessment of radionuclide transfer from the geosphere to biosphere domains, taking account of environmental change and to develop guidance on site characterisation needs at different types of site, as regards the near-surface features. The project may determine the couplings between environmental change and processes affecting radionuclide transfer across, and accumulation within, the GBIZ; investigate the quality of information regarding these processes over various timescales and at different site types, and hence determine where key uncertainties remain and potentially model the GBIZ.

Another research area to be pursued relates to exploitation of the synergies offered by participation in BIOPROTA project to improve the development of conceptual and numerical biosphere models. A working group is being set-up to formulate objectives and a programme of detailed studies.

IX. SUMMARY

The BIOPROTA project is focused on key data requirements identified by a top down evaluation of assessment requirements, and not a generic compilation of available information. If initial investigation shows that the information required is not available, then the project may use such resources as are available to carry out the relevant research, in a collaborative cost-effective manner, in order to provide that information.

For the future, there are a number of issues that still need to be addressed. Within BIOPROTA there is an increased emphasis on providing a forum for examining outstanding issues in biosphere programmes and developing collaborative research projects to reduce outstanding uncertainties and support safety cases for waste disposal. The mutual support that BIOPROTA offers within a commonly focused project is intended to make 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. Other organisations are welcome to participate, further information is available from www.bioprota.com.

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