The International Atomic Energy Agency's Programme on Biosphere Modelling and Assessment (BIOMASS)

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Abstract.

The IAEA's Programme on BIOsphere Modelling and Assessment (BIOMASS) provided an international forum for information exchange, development and collaboration in the area of environmental assessment modelling. This paper contains a brief overview of the work and results of the three themes of BIOMASS, namely: radioactive waste disposal, environmental releases and biosphere processes. The BIOMASS programme started in 1996 and is being terminated in 2001.

1. INTRODUCTION

To predict the radiological impact of planned activities and possible accidental events related to the nuclear fuel cycle, it is necessary to be able to analyse and quantify the behaviour of radionuclides in the biosphere. In recent years two international programmes have been aimed at the improvement of methods for assessing the impact of radionuclides in the environment; the IAEA's Validation of Model Predictions (VAMP) programme and the BIOMOVS II (Biospheric Model Validation Study) supported by organisations from Canada, Spain and Sweden. The programmes served to provide fora for the promotion of international collaboration, information exchange and peer review in the area of modelling and assessment of the movement of radionuclides and other pollutants in the environment.

As a follow up to the VAMP programme, the IAEA launched a programme on BIOsphere Modelling and ASSessment (BIOMASS) in October 1996. The themes of the programme were as follows:

Theme 1: Radioactive Waste Disposal. The objective of this theme was to develop the concept of "Reference Biospheres" into a practical system for application to the assessment of the long-term safety of repositories for radioactive waste.

Theme 2: Environmental Releases. This theme had the objective of testing and comparing models for the assessment of radiation exposure related to environmental releases. Two Working Groups were established concerned with: Dose Reconstruction for previous releases; and Remediation Assessment to evaluate the efficacy of remedial measures.

Theme 3: Biosphere Processes. The aim of this theme was to improve capabilities for modelling the transfer of radionuclides in particular parts of the biosphere which have been identified as being of potential radiological significance. Three working groups were established to examine modelling of: 1) the environmental transport of tritium; 2) radionuclide uptake by fruits; and 3) radionuclide migration and accumulation in forest ecosystems.

In this brief paper which draws on the preliminary reports of the various BIOMASS working groups it is only possible to give an indication of the nature of the work of the programme.

2. BIOMASS THEME 1 - REFERENCE BIOSPHERES

2.1. Background

The safety principles, including radiological protection objectives, that apply to radioactive waste are well established. There is, however, little consensus on how compliance with these principles is to be demonstrated for releases to the environment that might take place in the distant future. This is of particular relevance to the geological disposal of long-lived radioactive waste, where releases of radionuclides could occur thousands of years after repository closure.

The consequences for human health of a radionuclide release require consideration of the prevailing biosphere system, including the humans within it. A good example relates to food consumption. Here radiological impact depends on the quantity and type of food consumed and the associated levels of contamination by radionuclides - factors that mostly depend upon the biosphere system, its spatial relationship to the source of contamination and the habits of the potentially exposed humans that inhabit the system. To carry out these calculations, it is usual to construct mathematical biosphere models (called 'assessment biosphere' here) based on the features, events and processes that are known to occur within existing, and relevant, biosphere systems.

Complex biosphere systems that actually exist can be studied, understood and modelled. The biosphere systems that will exist in the far future, however, will be shaped by unknown technological advances and complex interactions between natural forces. These future biospheric systems cannot be predicted, not in any testable way, at least, and can only be studied by reference to present day or historical examples. This difficulty means that assessment biospheres that are intended to apply to the far future will be largely hypothetical, albeit that they will be constrained by knowledge of the past (and possible future) evolution of a site. A typical approach is to construct a series of assessment biospheres based on site-specific and analogue data, to broadly represent a range of possible futures. However, faced with almost infinite possibilities, the difficulty lies in providing assurance that the modeled outcome is both robust and reasonable. Reference biospheres, if based on a good scientific appreciation of the key issues and a wide consensus as to what is reasonable, could be a useful way of providing this assurance. This approach broadly corresponds to the suggestion of the ICRP that assessment biospheres should adopt a stylised approach based on general (human) habits and (biosphere) conditions.

2.2. Methodology

A BIOMASS methodology has been developed which provides a formal procedure for the development of assessment biospheres, based on a staged approach in which each stage introduces further detail so that a coherent biosphere system description and corresponding conceptual, mathematical and numerical models can be constructed. The methodology is presented schematically in Figure 1 (although this figure does not reflect the important role of iteration in the methodology).

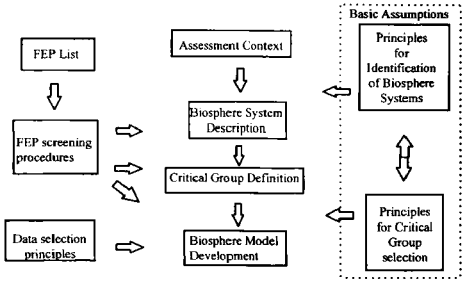

Figure 1: The Reference Biosphere Methodology

2.3. Possible application of Reference Biospheres

- Reference biospheres may be used to complement site-specific assessment biospheres by providing assurance that the latter are both robust and reasonable.
- Reference biospheres may be used generically e.g. for comparing the levels of safety provided by different disposal concepts when it might be inappropriate to use data based on site-specific information.
- Reference biospheres may be used as standards to facilitate cross-comparison and checking of results.

3. BIOMASS THEME 2: ENVIRONMENTAL RELEASES

3.1. Dose Reconstruction Modelling

Two scenarios were considered related to:

— an inadvertent release of ^{131}I to the atmosphere from the Hanford Purex Chemical Separations Plant in September 1963 (the Hanford scenario), and

— an area of ^{137}Cs contamination of the catchment basin and agricultural area of the Iput River basin, in the Bryansk Region of Russia, resulting from the Chernobyl accident in April 1986 (the Iput scenario).

The Hanford scenario served as the basis for calculations of atmospheric transport, deposition, and doses to humans from ^{131}I from external and internal exposure pathways. In the spirit of a true dose reconstruction, all available measurements were provided to modellers, even though the data were incomplete or not fully representative. Most of the attention of this group was focused on the atmospheric transport part of the scenario, and a variety of approaches were used to estimate transport and deposition at several specified locations.

Work on the Iput scenario gave participants valuable experience in assessment of the long-term radioecological situation for a local area highly contaminated with a long-lived and biologically active radionuclide, ^{137}Cs. In particular, it allowed the effects of countermeasures, and a combination of terrestrial and aquatic pathways of exposure to be considered. Modelling endpoints included ^{137}Cs concentrations in food products and animal feed, human whole body concentrations, and average internal and external doses to residents of the region.

Conclusions

- For both scenarios, model predictions were found to be strongly dependent on the judgment of the modeller in the selection of parameter values or interpretation of input information.
- The complexity of a model employed in dose reconstruction assessments should be in accordance with the availability of input information. Use of complicated models that rely on large amounts of data may lead to unreliable results when such data are absent, as is often the case in a dose reconstruction exercise.
- The Iput scenario exercise gave modellers experience in modelling and understanding the complex nature of agricultural countermeasures. The need to consider effects of countermeasures on radionuclide bioavailability, the duration of effect in time, saturation effects, and indirect effects on the fertility of agricultural lands was identified.
- The current state of radioecological modelling is such that some specific processes are described completely and are well documented, whereas other processes are described empirically or are poorly documented. For example, models of ^{137}Cs downward migration in soils are incomplete and lead to some inaccuracy in estimation of the soil-to-plant transfer factors in this exercise. Furthermore, situations were encountered where parameter values were scarce, e.g., transfer factors for natural food products (mushrooms, wild berries).

3.2. Remediation Assessment Modelling

Two scenarios were constructed and applied based on the contamination around the site of a former radium extraction plant in Olen, Belgium.

Olen Scenario Type A considered the influence of a past remedial action, particularly the effect of deep ploughing (over a depth of approximately one meter) of land subsequently used as pasture land for dairy cows. The effects on radium concentrations in cow's milk during the period 1971–1972 were assessed and compared with post-remediation measurements.

Olen scenario Type B considered the effectiveness of potentially feasible remedial actions on the doses experienced by the local population. The land area considered in this scenario is currently pasture on which dairy cows are grazed. A number of possible remedial actions were identified that could lead to the unrestricted use of the land.

Conclusions

For the Type A scenario, the predicted radium concentrations in milk were in general overestimated by around one order of magnitude. This may be the effect of the scenario description; it may imply that the radium measurements in soil represent maximum rather than average values, or that the radium contamination of the soil did not penetrate to as great a depth as assumed. Alternatively, it may be the result of modellers using conservatively biased parameters throughout the modelling process.

Differences between model predictions were mainly due to differences in user interpretation of the scenario description. The main sources of uncertainty were the radium distribution in the root zone before deep ploughing and the effectiveness of deep ploughing. The differences due to the use of different calculational methods were limited and the more dynamic models did not necessarily perform better than the simple equilibrium models.

In the case of the Type B scenario, the differences amongst the model predictions are mainly due to differences in interpretation rather than due to differences in modelling approach. The calculation of the radon concentration in- and outdoors and the lead concentration in soil were the main challenges. There are several parameters that influence radon concentrations in- and outdoors, for example, the current state of buildings, the ventilation rate, the type of soil, the homogenity of the soil, type of soil, and differences in treatment of these factors may lead to very different results.

4. BIOMASS THEME 3: BIOSPHERE PROCESSES

4.1. Modelling the Environmental Transport of Tritium

Two main approaches were used to test models simulating transfer to the environment following the atmospheric release of HTO and HT. Firstly, three scenarios were defined that served as a basis for model-model inter-comparison exercises. Secondly, the experimentalists provided data for three model validation exercises. Moreover, a specially commissioned experimental programme was carried out at Bruyeres le Chatel in France in parallel to the modelling exercises. A sampling survey and analysis programme carried out over a twenty-month period was specifically dedicated to deriving information and data for a key issue on tritium behaviour. Results from modelling exercises and the experimental programme were discussed at meetings and models were tested, developed and refined through individual work and multi-lateral exchanges between participants.

Conclusions

Modelling

1. Dry deposition is an important process that contributes to long-term average soil moisture concentrations of HTO and should be included in models.
2. Secondary sources of HTO due to re-emission from soil can be ignored for ground-level atmospheric sources and at distances >500 m from elevated sources but must be considered if the source is sub-surface.
3. To calculate near-surface soil moisture concentrations due to an atmospheric source, a more accurate estimate is made if soil moisture concentrations are related to air rather than rain concentrations.
4. For HT releases, air and near-surface soil concentrations of HTO can be obtained from empirical data obtained in the chronic HT release experiment.

Data Acquisition Methods

1. It is essential to have good source data and accurate measurements for model inputs (e.g. well-defined meteorological data statistics, soil properties) in order to achieve good assessment predictions.
2. Sampling programmes should be planned to yield mean concentrations, which are the quantities of primary interest in dose assessments.
3. Models can be used to highlight problems with observational data and it should not be automatically assumed that model predictions are inaccurate if they do not agree with the observations.

4.2. Modelling Radionuclide Uptake by Fruits

The overall aim of the Fruits Working Group activities was to improve understanding of the processes affecting the migration of radionuclides in the fruit system and reduce the uncertainties associated with modelling the transfer of radionuclides to fruit. This would improve the robustness of the models that are used for radiological assessment and increase the confidence with which they are applied. The overall aim was met by a programme of work with six subsidiary objectives: to promote discussions between modellers and experimentalists, to review the literature on radionuclide transfer to fruit, to develop a data base of model parameter values, to undertake model intercomparisons, to identify, encourage and coordinate experimental studies on radionuclide transfer to fruit, and to undertake testing and validation of existing or new models against independent data sets. Progress has been made in all of these areas and, in particular, the results of the literature review were published in the Journal of Environmental Radioactivity earlier this year.

In relation to model comparison and testing, difficulties were encountered because of the lack of models specifically designed to predict the behaviour of radionuclides in fruits and because of the lack of data useful for a validation study. Nevertheless, a model-model intercomparison exercise was organized which involved six models. Two scenarios were developed by the Group, one for acute releases and one for continuous releases and were concerned with transfer to apple, blackcurrant and strawberry of Cs, Sr and I. Results showed large differences in model predictions of radionuclide accumulation in fruits for the long-term time scales, while short-term predictions can be satisfactorily modelled with an uncertainty of about one order of magnitude. A comparison of differences in the assumptions in the various models reveals that some of the processes are treated similarly by most of the models, while others are treated very differently. Results clearly indicate the need for further development of models for the fate and transport of radionuclides in fruit ecosystems. For model validation purposes, a scenario was developed based on an experimental acute release of Cs and Sr on strawberry plants. This was the first model validation exercise for fruit crops. Participants were able to assess their model performance and benefited from discussions on processes and assumptions.

4.3. Modelling the Migration and Accumulation of Radionuclides in Forest Ecosystems

The BIOMASS Forest Working Group addressed a number of issues relevant to the improvement and validation of existing models which are designed to predict the behaviour and fate of radionuclides, principally ^{137}Cs, in forest ecosystems. In addition, reviews have been undertaken concerning our fundamental understanding of biogeochemical cycling in forest ecosystems, the use of interaction matrices in model design and process identification, and the definition and application of the transfer factor concept in forest ecosystems.

Major conclusions from reviews

- More data sets addressing radiocaesium cycling within forests on a whole ecosystem basis would be useful to aid model development and validation.
- An alternative way to improve the development of conceptual models is the application of a systematic method of identifying dominant features, events and processes (FEPs) using an 'interaction matrix' approach.
- The definition of transfer factors suitable for application to perennial woody vegetation such as trees remains problematic because the radionuclide burden of wood may have been accumulated over a period of several decades and single TF values may not adequately reflect this.
- A novel method to determine the wood interception potential (WIP) for radiocaesium has been proposed.

Some conclusions from model inter-comparison exercises

- For the soil and tree compartments examined there was generally a high level of consistency between predictions made by the 11 models tested. Predictions of all the biological endpoints proved more variable, especially predictions for mushroom contamination.
- There is clearly still a need to keep adding to existing data sets to ensure that the genuinely long term trends of ^{137}Cs distribution in forests are recorded and understood.
- The key conceptual question which arose when considering a subterranean source term of ^{137}Cs, was whether vertically upward transport of ^{137}Cs in a soil profile is best considered as a physical process or as a biologically mediated process, especially in the presence of deep-rooting trees.

5. BIOMASS - FINAL REMARKS

The reports of the BIOMASS study are currently being finalized and it is planned that they will be issued as part of the IAEA's Technical Document series (TECDOCs). IAEA Member States have indicated their continued support for programmes of the BIOMASS type and discussions will take place later this year on possible themes for a new international biosphere modelling programme.

Acknowledgments

The Chairpersons of the BIOMASS working groups were I. Crossland, UK, (Reference Biosphere) K. Thiessen, USA, (Dose Reconstruction), L. Sweeck, Belgium, (Remediation), Y. Belot, France, (Tritium) F. Carini, Italy, (Fruits), G. Shaw, UK (Forests).