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NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE

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Integration Group for the Safety Case (IGSC)

The Role of the Biosphere in a Safety Case
IGSC TOPICAL SESSION at the third IGSC Meeting

24th October 2001

English - Or. English

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FOREWORD

A Topical Session focused on the **"Role of the Biosphere in a Safety Case**" was organised in the framework of the 3rd meeting of the IGSC (Integration Group for a Safety Case). This held in Paris, France on 24th October 2001.

48 participants represented several national waste management organisations, regulatory authorities, from 15 OECD member's countries, IAEA and EC.

The Topical Session focused on the recent scientific developments in international programs such as IAEA BIOMASS, EC BIOCLIM, the views of regulators and the strategies being adopted by several implementers for incorporating the biosphere in their safety assessments.

This paper deals with a synthesis of the different oral presentations and the various exchanges during the session as well as a compilation of the written contributions. It is intended to provide a state of the art overview of the different manners on how to be involved in the biosphere, either from research, implementer or a regulator body.

ACKNOWLEDGEMENT

The NEA expresses its gratitude to:

- Jesus Alonso (ENRESA, Spain) who chaired the Topical session;
- Sean Russell (OPG, Canada) who co-chaired the topical session as a rapporteur;
- The speakers for their interesting and stimulating presentations as well as for their written contributions
- The IGSC participants for their constructive participation.

The proceedings were prepared by Sean Russell with the collaboration of Sylvie Voinis (NEA secretariat) and reviewed by Jesus Alonso and Abe van Luik (chairman of the IGSC).

TABLE OF CONTENTS

AGENDA OF THE TOPICAL SESSION ON THE SAFETY CASE

Wednesday 24 October 2001

Introduction	*J. Alonso*	*Chairman*

Part A: Technical bases

IAEA BIOMASS project	*Phil Metcalf*	IAEA, Austria
	Ian Crossland	UK-Nirex Ltd, United Kingdom
EC / BIOCLIM project	*Marianne Calvez*	ANDRA, France

Part B: Regulation Considerations

Regulator Workshop of Sept. 2001	*Mikael Jensen*	SSI, Sweden

Part C: Implementers Strategy

Posiva's Strategy	*Aimo Hautojarvi*	Posiva Oy, Finland
	Timo Vieno	VTT Energy, Finland
Yucca Mountain Strategy	*Abe Van Luik*	US DOE/YM, USA

PART A

SYNTHESIS

Introduction

The safety case is a collection of arguments at a given stage of repository development in support of the long-term safety of the repository. The safety case comprises the findings of a safety assessment and a statement of confidence in these findings. The biosphere is one of the features of a geologic repository system for the long-term management of radioactive waste. The biosphere is important in a safety assessment since it is the place where humans and most organisms live and where regulations are made.

Generally speaking, the biosphere is more dynamic than the geosphere and its evolution with time can significantly affect dose estimations and potential impacts of a geologic repository (e.g., climate change, glaciation, civilisation movement, etc.). That is, other parts of the repository system (vault, geosphere) are more robust or constant in time than the ever changing biosphere. Most of the variability associated with future events in the biosphere is driven by climate change. Climatic change and the characteristics of future societies are important sources of uncertainties Biosphere. Uncertainty can be addressed using reference or example biospheres, or alternative safety indicators such as radionuclide concentration or radionuclide flux from the geosphere to the surface biosphere (as indicated by the recent regulatory guidance in Finland), or by comparing predicted radionuclide concentrations from a repository with background levels in the environment.

Thus, a Topical Session that focused on the "The Role of the Biosphere in a Safety Case" was organised in the framework of the 3rd plenary meeting of the IGSC. This was held in Paris in France on 24th October 2001. This Topical Session reviewed the role of the biosphere in a safety case for geologic disposal of radioactive waste and discusses recent developments in international programs (IAEA BIOMASS, EC BIOCLIM), the views of regulators and the strategies being adopted by several implementers for incorporating the biosphere in their safety assessments. It also included one presentation on a peer review as a tool to build confidence in a safety case through an improvement of the comprehension on the biosphere and its role in a safety case.

48 participants represented several national waste management organisations and regulatory authorities from 15 OECD member's countries and the IAEA.

The Topical Session was split in three parts:

- Part one related to the scientific bases on the biosphere;
- Part two was concerned with the regulators requirements; and
- Part three aimed to present some examples as regards the implementers strategies.

The Chairman of this topical Session was Jesus Alonso (ENRESA, Spain). The rapporteur was Sean Russell (OPG, Canada).

The current synthesis presented in Part A is aimed at briefly reflecting the material presented at this Topical Session and providing a short overview of its main outcomes. The written contributions are compiled without further elaboration from the Secretariat, in Part B of the document. Part C gives the list of participants at this Topical Session.

All the overheads of the topical session are available upon request from the NEA secretariat.

BACKGROUND

The International Commission for Radiological Protection (ICRP) formulates fundamental radiation protection recommendations from a non-governmental organisation. Radioactive waste recommendations was recognised as one area that needed new developments by the ICRP, due to the difficulties in the application of radiation protection principles to waste disposal facilities[1]. In that context, ICRP 46[2] and then 81[3] paid attention to the specific problems raised by the concept of disposal of long-lived solid radioactive waste. ICRP acknowledges the basic principle *"that individuals and populations in the future should be protected at least at the same level of protection as is the current generation*" established in the IAEA Safety Fundamentals 111.

The application of radiological protection objectives by national organisations in the context of the safety performance of geologic disposal for radioactive waste is interpreted by including some form of limitation to these potential radiation doses and risks. Thus, the biosphere might play an important role in the integrated performance assessments with a view of providing an evaluation of the impact of potential releases of radionuclides from the waste form to the biosphere. As mentioned in the IPAG 3[4] exercise, "*no one considers the biosphere to be a barrier but many see it as providing safety functions* ". The function of the biosphere is mainly interpreted to act as a form of "measuring instrument" for evaluating representative radiological impact indicators of potential releases from the repository. Although when modelling the transport of radionuclides into and through the biosphere account is also given in some cases, for dilution and dispersal processes that may reduce considerably dose estimations in safety assessments.

The main release of radionuclides to the biosphere might occur more than several thousand years after closure of the repository. The inherent unpredictability of human actions as well as the uncertainties related to the evolution of climates during the long lifetime of a deep repository presents problems for the identification of future environmental systems and the determination of potential exposure pathways. As mentioned in the 1999 NEA report[5], it has been recognised that the nature of performance assessments in different time frames cannot be the same and in particular uncertainties increase with time. Therefore, the results from safety assessments need to be regarded as indicators of the safety rather than as real predictions of impacts and the biosphere can be thought as *"a set of assumptions and hypotheses that is necessary to provide a consistent basis for calculations of the radiological impact arising from long term releases"* [6].

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1. Jean Claude Nénot, ICRP policy for radioactive waste disposal, Topical Session proceedings on Safety Case, 3rd IGSC meeting on 25th of October 2001, NEA/RWM/IGSC (2002) 1.
2. ICRP 46, Radiation Protection Principles for Disposal of Solid Radioactive Waste, volume 15, n° 4, 1985, Pergamon Press.
3. ICRP 81, Radiation protection Recommendations as applied to the Disposal of Long-Lived radioactive waste, Volume 28 N°' 1998, Pergamon Press.
4. IPAG 3 : Working Group for the Integrated Performance Assessments of Deep Repositories; " Approaches and Arguments to establish and communicate confidence in safety", NEA/RWM/IPAG (2001)REV, Dec 2001
5. Geological disposal of radioactive Waste , Review of Developments in the Last Decade, NEA 1999
6. BIOMASS programme ; Long term releases from Solid Waste Disposal facilities: the concept reference biosphere concept, BIOMASS THEME 1, working document n°1, IAEA, April 1999

Any description of the biosphere used in a long-term performance assessment could appear arbitrary. On an international level, an important effort was made to develop reference biospheres and to demonstrate that, if they are based on a good scientific understanding of the key issues, they could be used for the purpose of safety assessment. Progress was made thanks to the BIOMOVS and BIOMASS programmes. BIOMOVS[7] and particularly BIOMOVS II, focused on the development of a systematic process called the 'Reference Biosphere Methodology' for establishing a logical audit trail to justify the scope, constituents and definition of assessments biospheres. BIOMASS[8] aims to augment and complete the Reference Biosphere Methodology and to develop a subset of example assessment biospheres to illustrate the methodology developed. As said in BIOMASS "*a reference biosphere is a stylised assessment biosphere, intended to be widely applicable in the context of the total system performance assessment of disposal facilities for long lived radioactive waste."* The set of examples go from a simple "drinking water well" intruding into an aquifer, to a multiple natural groundwater interface, passing through to a case with a complete agricultural environment with a well interface. The different examples developed under BIOMASS showed the importance to provide a clear assessment context, to clarify intentions and support a coherent biosphere assessment process within the overall safety assessment.

The need for environmental change to be considered in an assessment is also introduced in the Reference Biosphere Methodology through the identification and justification of biosphere systems. The selection of a continuous evolving system or a discrete approach is discussed within the context and requirements of each specific assessment.

As mentioned in IPAG 3, "many assessments didn't consider any changes with time but many reviewers have considered approaches with generic, non-specific, well dilution factors to be insufficient". An EC project BIOCLIM[9] started in 2001 with an objective of providing a robust scientific basis and practical results to investigate how climate and related environmental changes can be represented in radiological performance assessments.

In 2000, NEA/RWM/PAAG (99) 5 document further explores the role of the analysis of the biosphere and human behaviour in safety assessments with a view to stimulating discussion and to identify further work that may be needed in this area. At least, in the IGSC Foundation and planning document it was suggested that IGSC would receive a report on international initiatives on biosphere issues by means only of reports by individual(s) to plenary. Thus, this Topical Session was organised under the IGSC auspices to address the role of biosphere in a safety case. It aims to present the findings from different fields that are concerned under the item "biosphere" such as the scientific aspects under the international initiatives, a view of regulators' requirements and some strategies' example of waste management organisations. The Chapter hereafter summarises the presentations and discussions that took place during this session.

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7. BIOMOVS: International programme on the BIOspheric Model Validation Study

8. BIOMASS: IAEA project on BIOsphere Modelling and Assessment.

9. BIOCLIM: On going EC BIOCLIM Project (2000-2003) 5th Euratom Framework Programme- Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal.

Summary of presentations

Jesus Alonso (ENRESA, Spain) opened the Topical Session by giving an overview of the various aspects regarding the role of biosphere in a safety case. Firstly, he reminded that the biosphere is a natural system, and its evolution is mainly driven by climatic change. The biosphere is a dynamic system and it is difficult for safety assessment specialists to justify the values assigned to the many biosphere parameters used to assess doses in the future. Regarding the safety function, he mentioned that the biosphere has no real confinement function but it plays an important part in the safety case by having an influence on the impacts of radionuclide releases through dilution and dispersion effects. He also suggested that the new ICRP requirements have to be considered in a safety assessment. Moreover, one key difficulty for the treatment of the biosphere corresponds to the treatment of the geosphere/biosphere interface. He reminded that there are controversies in the approaches to model the biosphere regarding the level of complexity needed for the models (e.g., simple, stylised and static with time versus time evolving biosphere). At least, he noted that some proposals tend to avoid the problem through the use of other "safety indicators" such as concentration of radionuclides or flux of radionuclides from the geosphere to the biosphere. However, organisations must be aware that the use of indicators need to be consistent with the regulatory requirements

Then, Phil Metcalf and Ian Crossland presented the IAEA BIOMASS project. Phil Metcalf explained that the BIOMASS project, begun in 1996, by an international forum organised by the IAEA was a very good exercise for exchanging information through technical meetings and documentation such as BIOMASS newsletters or CD ROM. Ian Crossland continued by giving a presentation of the BIOMASS theme 1 that concerns the radioactive waste disposal topic. Its objective was mainly to develop the reference biosphere methodology and to demonstrate its usefulness through some exercises related to the development of a practical set of example biospheres such as:

1. drinking water well,
2. agricultural irrigation, with a well source and
3. Set of natural groundwater discharges to natural, seminatural systems.

Input data would always change to accommodate a given repository simulation and location. Thus this project must be seen as a good exercise for the application of a methodology and should be considered as a good source of reference biospheres that might be viewed as a benchmark for comparison with site-specific safety assessments for a selected number of radionuclides. The main conclusion from the BIOMASS theme 1 project was that there appears to be an international consensus on preparing generic reference biospheres for postclosure safety assessment but waste management organisations should also consider the specific requirements of regulators and other stakeholders.

Marianne Calvez (ANDRA, France) presented the new EC BIOCLIM project that started in 2001. Its main objective is to provide a scientific basis and practical methodology for assessing the possible long-term impacts on the safety of radioactive waste repositories in deep formations due to climate driven changes. She explained that BIOCLIM objective is not to predict what will be the future but will correspond to an illustration of how people could use the knowledge. The BIOCLIM project will use the outcomes from the BIOMASS project. Where BIOMASS considered discrete biospheres, the BIOCLIM project will consider the evolution of climate with a focus on the European climate for three regions in the United Kingdom, France and Spain. The consortium of BIOCLIM participants consists of various experts in climate modelling and various experts and organisations in performance assessment. The intent is to build an integrated dynamic climate model that represents all the important mechanisms for long-term climate evolution. The modelling will primarily address the next

200000 years. The final outcome will be an enhancement of the state-of-the-art treatment of biosphere system change over long periods of time through the use of a number of innovative climate modelling approaches and the application of the climate model outputs in performance assessments.

With regards to the regulator's aspects, Mikael Jensen (SSI, Sweden) presented the feedback of the regulatory workshop that took place in Sweden in September 2001, titled “The Role of Future Society and Biosphere in Demonstrating Compliance with High-level Radioactive Waste Disposal Standards and Regulations”. The theme included questions such as how to meet regulatory compliance with an evolving biosphere and how will regulators judge compliance? During the Workshop, presentations were made from international regulatory aspects such as IAEA or ICRP. There were also very interesting country-by-country presentation such as the Finnish presentation by STUK which specifies limits on radionuclide releases from a repository after a thousand years or so. There appears to be a consensus on the relevance developing initiatives on the sustainable development, the protection of the environment and addressing long time scales. One technical aspects, the geosphere/biosphere interface, was viewed as a key issue for future study and analysis.

Regarding the waste management organisation strategies, Aimo Hautojärvi (Posiva, Finland) explained that Posiva follows the regulation from authorities that will be published soon on the STUK Website in an English version. As an example, he said that a dose constraint of 0.1 mSv/a must be considered for several thousand years and release rate constraint for the long term. The values for these constraints were given by STUK and Posiva needs to demonstrate compliance. Posiva welcomes the regulator’s clear requirements and guidance in the field of biosphere analyses. Moreover, Aimo Hautojärvi presented the planned future work that will be carried out by Posiva. As well as carrying out biosphere modelling for potential recipients at Olkiluoto, Posiva will conduct biosphere analyses for wells, lakes, seas, etc., and further evaluate human actions and develop biosphere models in close co-operation with SKB. Posiva is also actively seeking international co-operation in these new researches fields, for example within IAEA. Two potentially problematic radionuclides were also mentioned: C-14 and Radon plus decay products. These two radionuclides will be studied in depth in the future Posiva research and development programme.

Abe van Luik (USDOE- YM, USA), ended the presentation by giving feedback from the IAEA peer review on the biosphere modelling strategy developed by the DOE Yucca Mountain Site Characterisation Office (YMSCO). This review was based on available international standards and guidance. The peer review team was constituted of both experts from regulatory and waste management organisations and national advisory committees. The implementation of the review consisted of an examination of biosphere reports mainly regarding the modelling and question and answer exchanges. The final report was submitted in April 2000. It contained twenty-three recommendations within two broad classifications; one concerning the regulatory framework, the other one regarding the framework to increase stakeholders' confidence in modelling. The three main categories of recommendations were outlined, namely (i) the DOE' s Biosphere assessment Approach, (ii) the definition of the biosphere system, and (iii) the model development, data and results. Regarding in particular the treatment of the uncertainties in the biosphere, it was viewed as a key issue during the review and thus it will be re-evaluated in the future performance assessment. The summary highlighted most of the recommendations received are to be acted on, and are to be included in the License Application plan for biosphere modelling.

Conclusions

The Topical Session on the Role of the Biosphere in a Safety Case brought together a number of important issues from the perspective of radioactive waste management implementers, regulators and other stakeholders. The biosphere is important in a safety assessment since it is the place where humans and most organisms live and where regulations are made. The biosphere is more dynamic and changing than other components of the disposal system, such as the geosphere, and thus the evolution of the biosphere with time can significantly affect dose predictions to humans and the natural environment, and can potential affect a repository for radioactive waste. The general conclusions from the Topical Session were:

- The principal variability in the biosphere is driven by climatic change. This as well as uncertainties introduced by other factors such as life styles and human actions has a consequence; future biospheres cannot be predicted with confidence. Nevertheless the estimations provided for a range of scenarios reasonably defined can provide an appropriate basis for decision making.

- Biosphere uncertainty can be addressed by using reference, example biospheres, or alternative safety indicators such as radionuclide concentration or radionuclide flux to the biosphere (as indicated by the recent regulatory guidance in Finland) and comparing these values with background levels in the environment near the repository.

- Most safety assessments have been conducted within the context of a reference, time-invariant biosphere in order to provide an *indication* of safety rather than an attempt to predict actual doses in the future.

- There is a movement in some waste management organisations towards developing time-evolving biospheres to complement the models that use static biospheres such as the well scenario or the agricultural scenario defined in BIOMASS. One example of work in evolving biospheres can be found in the BIOCLIM Project with the European Commission, which addresses how to consider climate change consequences in performance assessments.

- It is apparent that the radioactive waste management community needs to seek broader input from the long-term climate evolution community in order to improve its credibility among experts in this field. The BIOCLIM project, and other waste management initiatives in climate change will address this need and will most likely result in a better understanding of biosphere evolution and how to incorporate it into the safety case.

- Some regulators feel that they are under pressure to make detailed decisions on geologic repository compliance far into the future. Also some stakeholders are expecting waste management organisations to make real predictions of the future evolution of the biosphere and impacts from a repository on humans and the natural environment. In this respect it is essential to clarify the NEA safety case concept, which consist of collective arguments in support of long-term safety of a repository, intended to provide the basis for decision making. The meaning of estimations of future doses, which is not to be understood as actual doses, should be clarified further following ICRP guidance.

- The connections between a regulatory guidance, waste management organisation strategies and scientific studies on the biosphere are not always clear. There are differences in regulatory guidance and regulatory requirements among the countries practising waste management, which need to be resolved in order to avoid confusion amongst stakeholders. Nevertheless, progress is being made in this area through international meetings and workshop initiatives.

- International guidance from the ICRP is evolving on topics such as environmental protection, human intrusion, collective dose, optimisation and ALARA. Clarity on these issues will be very useful to regulators and implementers. The publication ICRP number 81 is oriented in this line with useful practical guide.

PART B

COMPILATION OF THE PRESENTATIONS

(Please note that the overheads of the presentations are available upon request from the NEA secretariat)

11-13 September 2001

Carlos Torres Vidal
Waste Safety Section
OIEA

C.Torres@iaea.org

Workshop on The role of future society and biosphere in demonstrating compliance with high-level radioactive waste disposal standards and regulations, Stockholm, 11-13 September 2001

Organized by :Swedish Radiation Protection Institute, SSI and the U.S. Environmental Protection Agency, EPA

REFERENCE BIOSPHERES FOR LONG TERM SAFETY ASSESSMENT OF HIGH LEVEL WASTE DISPOSAL FACILITIES

Content:

There is nothing good or bad, but thinking makes it so
William Shakespeare

This paper introduces the Agency project on biosphere modelling and assessment (BIOMASS) and summarizes the work done in the *Biomass theme 1 on radioactive waste management* during the last five years. The author coordinated the Bioamass programme and acted as scientific secretary of the Biomass theme 1. This Paper is a compilation of the results of the Agency work on "Reference Biospheres for Long Term releases assessment" . The conclusions reflect the consensus reached by more than 80 experts on the subject. The Agency is not responsible for any material reproduced in this document. The author acknowledges with gratitude his debt to D. Cancio (Ciemat), G. Linsley (IAEA), and to his colleagues/friends P. Pinedo (Ciemat), G. Smith, R. Little, I. Crossland, P. Coughthrey, , M. Egan and B. Watkins.

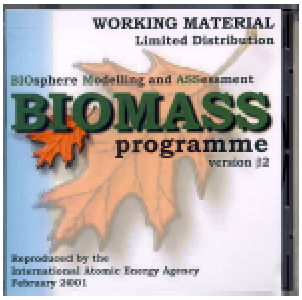
- In the past there were two principal international programmes aimed at the improvement of methods for assessing the impact of radionuclides in the environment; they are IAEA's VAMP programme and the BIOMOVS (BIOspheric Model Validation Study).
- In October 1996 the IAEA launched an International Programme on *Biosphere Modelling and Assessment Methods* (**BIOMASS**).

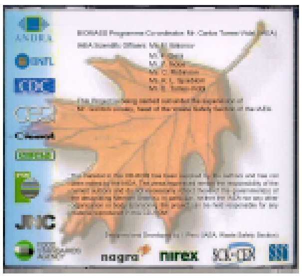
The last BIOMASS Research Co-ordination, Plenary and Working Group Meetings were held at the Agency's Headquarters in Vienna, 6–10 November 2000. As in previous years, the meetings proved to be very popular and were attended by more than 100 environmental modelling and assessment experts.

The BIOMASS CD-ROM contains general information about the Programme, previously distributed Newsletters and the Working Documents as approved during the November 2000 meeting. Furthermore, the CD-ROM also contains some further information relevant to biosphere modelling and assessment.

The final activity under the BIOMASS Programme will be a meeting of the BIOMASS Co-ordinating Committee, which will be held in Vienna during September this year. The Committee will approve the final versions of the BIOMASS documents and prepare the final conclusions from the Programme. In this regard, all of the final BIOMASS documentation will be made available by the Agency during 2002.

The Agency is currently preparing a new Programme on Biosphere Modelling and Assessment, which will take into account the results and conclusions from BIOMASS.





N.B: This paper was presented at the topical session by **P.Metcalf**, IAEA, Austria and **I. Crossland,** Nirex Ltd, UK.

The Agency Programme on Biosphere Modelling and Assessment (BIOMASS)

In order to assess the radiological impact of practices and interventions related to nuclear fuel cycle and other activities, including radioactive waste management, it is necessary to be able to analyse and quantify the behaviour of radionuclides in the biosphere. In the past there were two principal international programmes aimed at the improvement of methods for assessing the impact of radionuclides in the environment; they are IAEA's VAMP programme and the BIOMOVS (BIOspheric Model Validation Study) supported by organizations from Canada, Spain and Sweden.

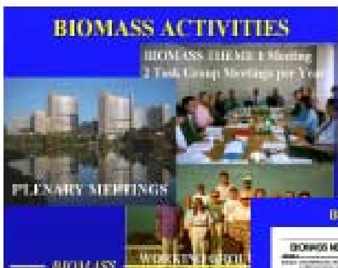
The IAEA's VAMP programme was established to take advantage of the opportunity offered by the fallout from the Chernobyl accident for testing the predictions of environmental models. Following this accident and on the recommendation of the international Nuclear Safety Advisory Group (INSAG), the IAEA established a Co-ordinated Research Programme in 1988 on "The Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban and Aquatic Environments and the Adquisition of Data for that purpose". The VAMP Programme was started in 1988 and terminated in 1994.

The BIOMOVS I programme was launched at a meeting in Paris, in 1986 and was completed in Stockholm 1990. BIOMOVS II, a follow up programme to BIOMOVS I, was started in October 1991 and finished in October 1996 in Vienna. The primary objectives of BIOMOVOS programmes were: (1) to test the accuracy of the predictions of environmental assessment models for selected contaminants and exposure scenarios, (2) to explain differences in model predictions due to differences in model structure, modelling assumtions and/or differences in selected input data and (3) to recommend priorities for future research to improve the accuracy of model predictions.

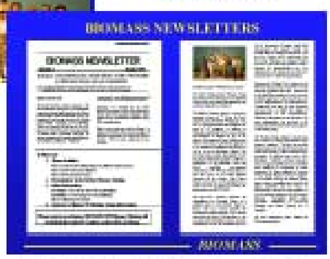
In October 1996 the IAEA launched an International Programme on *Biosphere Modelling and Assessment Methods* **(BIOMASS)**.

The Agency Programme on Biosphere Modelling and Assessment Methods (Biomas) was launched in Vienna in October 96. Around 100 representatives of 30 countries attended the firs BIOMASS

The programe aims to provide an international focal point in the area of biosphere assessment modeling and to develop and improve models and modeling methods for the analysis of radionuclide transfer in the biosphere for use in radiological assessments. The programme addresses important radiological issues associated with accidental and routine releases and solid radioactive waste management.



BIOMASS has been proved to be a very active project, more than 30 working meetings were held since 1996



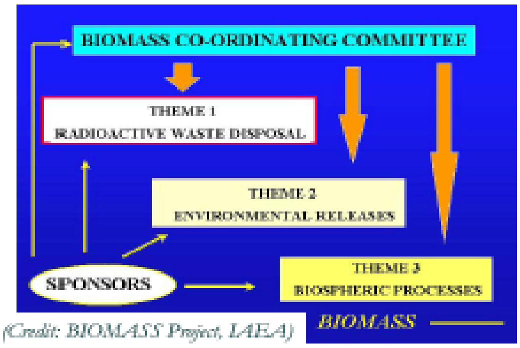
A collection of 8th newsletters have been produced (around 100 pages)

(Credit: BIOMASS Project, IAEA)

The Agency Programme on Biosphere Modelling and Assessment (BIOMASS)

BIOMASS programme ORGANIZATION

The IAEA is reponsible for the overall coordination of BIOMASS and it is the leading organisation for all external dealings associated with the study.



(Credit: BIOMASS Project, IAEA)

The programme is being carried out under the supervision of *Gordon Linsley*, head of the Waste Safety Section.

The coordinating committee is responsible for all decisions relating to the establishment of themes, working groups and their objectives. It continuosly review the overall progress of the study. It is responsible for all decisions on publications associated with the study. The IAEA is making an effort to ensure that the BIOMASS project and its documentation are finished and completed by the end of 2001. As part of this process the BIOMASS Steering Committee has been reinforced. *Mr. Ben Walters* (Food Standards Agency, UK) became its chairperson since 1999.

The sponsors organizations played an important role in the BIOMASS programme. They provided the Agency with the resources and the expertise needed for executing the BIOMASS project. They were always represented in the BIOMASS Co-ordinating Committee.

BIOMASS programme SPONSORS

Agence National por la Gestion des Dechets Radioactifs (ANDRA), France

British Nuclear Fuels plc (BNFL), United Kingdom

Centers for Disea Control and Prevention (CDC), USA

Commissariat a L'Energie Atomique (CEA), France

Centro de Investigaciones Energeticas Medioambientales y tecnologicas (CIEMAT), Spain

Empresa Nacional de Residuos Radiactivos SA (ENRESA), Spain

Food Standards Agency, UK

National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland

Institut de Protection et de Surete Nucleaire (IPSN), France

United Kingdom Nirex Ltd (Nirex), United Kingdom

Japan Nuclear Cycle Development Institute (JNC), Japan

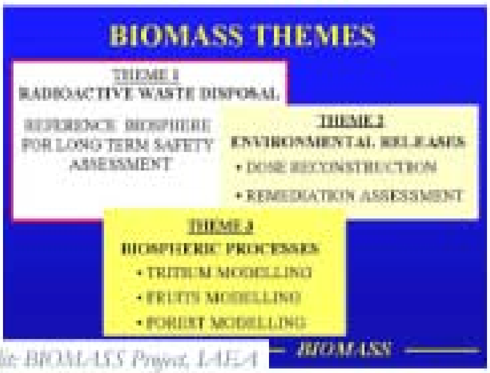
Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucleare, (SCK.CEN),

Statens Stralskyddsinstitut, Sweden

The Agency Programme on Biosphere Modelling and Assessment (BIOMASS)

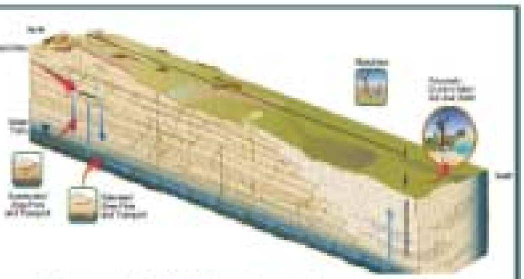
BIOMASS programme THEMES

BIOMASS covers three important themes related to environmental modelling and safety assessment.



Credit: BIOMASS Project, IAEA

Theme 1: Radioactive Waste Disposal. BIOMASS Theme 1 aims to develop the concept of "Reference Biosphere" into a practical system for application to the assessment of the long term safety of geological repositories for radioactive waste. A primary goal of the programme is to develop a subset of example reference biospheres, which can provide a useful point of reference as broadly applicable indicators of potential radiological impact for radionuclide releases ocurring in the long term.



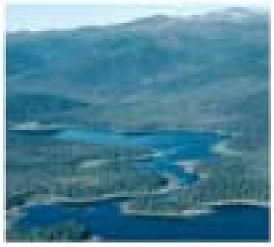
Potential Radioactive releases to the biosphere from a deep geological disposal Facility (Credit: DOE, USA)

Theme 2 : Environmental Releases, focuses on issues of dose reconstruction and remediation assessment. Many national agencies and authorities showed interest in addressing concerns about the effects of historic releases, both planned and accidental and in guiding decisions on alternative technologies and techniques available for remediation of contaminated sites. Two working group have bee established within BIOMASS Theme 2. The Dose reconstruction WG is concerned with the evaluation of the reliability of methods used for dose reconstruction for specific individulas and members of specific population subgroups. The Remediation assessment WG is aiming to evaluate the reliability of dose and risk assessment methodologies applied in support of decisions to determine the cost-effectiveness of risk reduction measures within an environmental remediation programme. The remediation assessment Test case cerned the radioactive contamination of a site (Olen, Belgium), brought about by a former radium plant, which was shut down in 1960.

The Working Group on Dose remediation used the inadvertent acute release of I131 to the environment from the Handford Purex Chemical Separations Plant ocurred on September 1963 as a Test

Theme 3: Biospheric Processes. The aim of this Theme is 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. This topic is being explored using a range of methods including reviews of the literature, model intercomparison exercises and where possible, model testing against independent sources of data. Three Working Groups have been set up, to examine modelling of: 1) long-term tritium dispersion in the environment; 2) radionuclide uptake by fruits; and 3) radionuclide migration and accumulation in forest ecosystems

The aim of the Fruits Working Group is to reduce the ucertainties associated with modelling the transfer of radionuclides to fruitand thereby to improve the robustness of the models



The forest Working Group objective is to enhance our ability to model the migration and accumulation of radionuclides in forest

Setting the scene: The Reference Biosphere concept

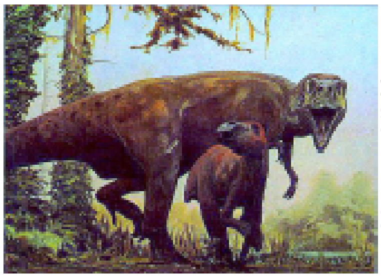
The application of radiological protection objectives in the context of the safety assessment of geological disposal systems for solid radioactive waste has been interpreted to include some form of limitation to the radiation doses and risks incurred by those people who may be exposed following closure of the repository. Consideration therefore needs to be given to the biosphere systems into which future releases might occur, as well as the behaviour of people in relation to such environments.

However, the inherent unpredictability of human actions presents problems both for the identification of future environmental systems and the determination of potential exposure pathways. As a result, there are significant difficulties in determining the precise radiological impacts, such as radiation dose and risk, in the long-term future, many hundreds or thousands of years after repository closure.

An human action transformed in less than 40 years a rich and populated lake ecosystem into a desert

Any description of the biosphere used in a long-term performance assessment could therefore appear somewhat arbitrary.

Biosphere systems cannot be predicted in the far future 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 may 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 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 sufficiently 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.



Biosphere systems that exist in the far future will be shaped by many natural forces and unknown technological advances.

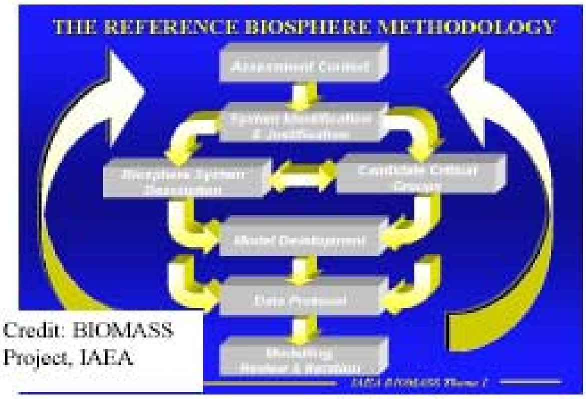
Another issue is that of standardization. In 1975, ICRP publication 23 stated that " although individuals vary considerably, it is important to have a well defined reference individual for estimation of radiation dose". The Commission hoped that such a reference individual would be recognized and used widely so that health physicists could compare and check their results without tedious enumeration of assumptions or without the risk of minor differences in these assumptions obscuring the basic agreement or disagreement of their results. Today we can say that 'Reference Man' was an important step forward in radiological protection, especially in the area of internal and external dosimetry. It might be similarly argued that, although future biosphere systems and associated potentially exposed humans cannot be predicted, it is important to have a well defined Reference Biosphere (with associated exposed humans) for estimation of radiation doses arising from long-term releases of radionuclides to the environment. As with Reference Man, wide use of Reference Biospheres would be helpful in cross-comparing and checking results.

Such thoughts suggest the following definition. A reference biosphere is a stylized assessment biosphere, intended to be widely applicable in the context of the total system performance assessment of disposal facilities for long-lived radioactive waste. Reference Biospheres serve three main purposes: providing generic biosphere information in the absence of site-specific data; providing assurance that assessment biospheres are both robust and reasonable, and serving as a standard to facilitate cross-comparisons and checking of results.

The BIOMASS methodology for deriving Reference Biospheres

The BIOMASS methodology 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)

4.1. Assessment context



Credit: BIOMASS Project, IAEA

Defining the assessment context is the first stage in the determination of a suitable assessment biosphere. This involves considering a number of fundamental issues that define the overall requirements, principally

- the purpose of the assessment;
- the endpoint of any assessment calculations;
- the site context;
- the radionuclide source term;
- the geosphere-biosphere interface;
- the timeframe of the assessment; and
- the assessment philosophy (e.g. the level of caution/conservatism to be applied).

While these issues may seem obvious, the fact is that they are sometimes left unspoken, raising the unwanted possibility that they could be decided arbitrarily.

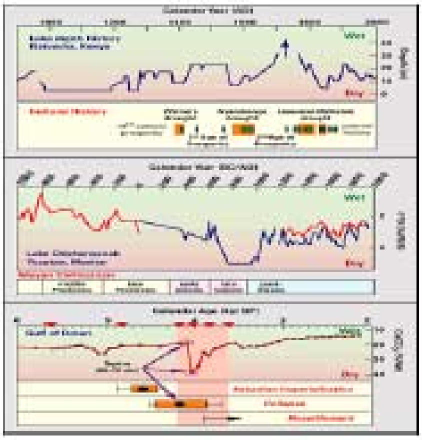
4.2. Biosphere system identification and justification

This stage of the methodology begins the process of creating an assessment biosphere based upon six Principal Components of the biosphere system: climate, geographical extent & topography, human activities, near surface lithostratigraphy, water bodies and biota. Biosphere system identification and justification takes place in four main steps.

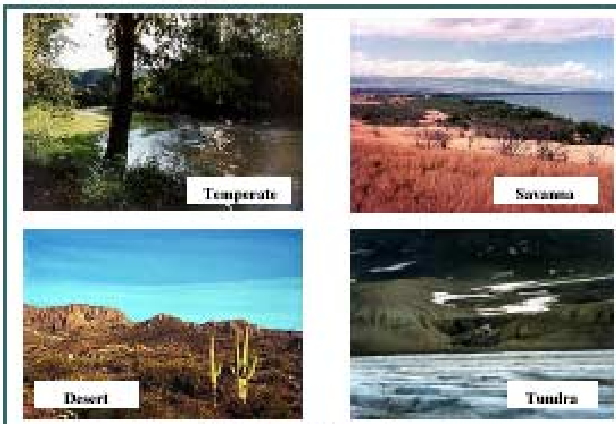
1. Identification (using a series of tables) of the type of Principal Component to be included within the assessment biosphere together with a explanation (justification) of the choice. For example, for the Principal Component 'water bodies', the identified Principal Component Types might be an aquifer and a river.

2. A decision on whether or not the assessment context requires biosphere change to be represented. In deciding this, two components of the assessment context are particularly relevant: the timeframe of the assessment and the geosphere-biosphere interface. At a coastal site, for example, it may be considered necessary to consider the effect of a change in sea level.

3. If biosphere change is to be represented, the third step considers possible mechanisms for change and their potential impact in order to identify (qualitatively) a range of possible future biosphere states.



4.- Finally, it is necessary to decide whether these possible future biosphere states are to be examined independently or in sequence. If the latter, then one might wish to consider different sequences or perhaps to focus on the transitions from one biosphere state to another.



Possible future biosphere states

The BIOMASS methodology for deriving Reference Biospheres (II)

Biosphere System Description

This stage of the methodology is aimed at providing sufficient detail about the biosphere system (or systems) to justify the selection and use of conceptual models for radionuclide transfer and exposure pathways. To begin, the methodology requires a decision to be made regarding the assumed level of human interaction with the biosphere system (for instance foraging in a natural or seminatural environment compared to intensive agriculture). Then, for each of the Principal Component Types, lists of potentially important characteristics (e.g. Table 1) are screened to determine a short-list of those thought to be relevant to the assessment. So using the example given previously, if an aquifer and a river were the identified Principal Component Types for the Principal Component 'water bodies', Table 1 would be used to describe the characteristics of the of the aquifer and the river that were to used in the assessment biosphere.

Water Bodies Characteristics

Geometry
- Level
  - Position
  - Variation (Global, Local)
- Basal characteristics

Flow rate
- Variation (e.g.: Permanent, ephemeral)

Suspended sediments
- Composition
- Load

Freeze/Thaw Phenomena
- Ground freezing
  - Seasonal
  - Long-Term (Permafrost, ice lens, etc.)
  - Snow pack development
- Water body freezing

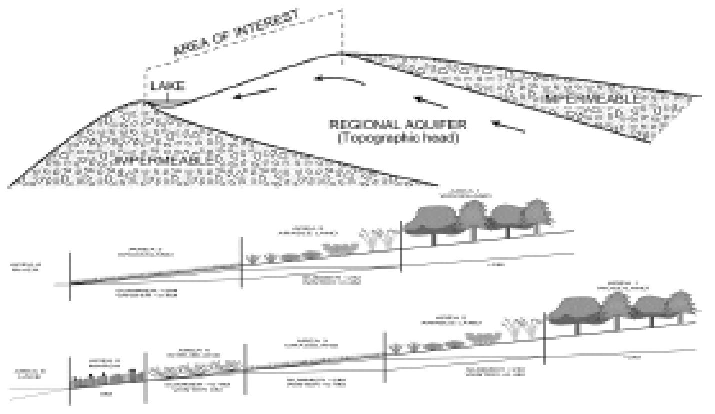
Hydrochemistry
- Composition of:
  - Major anions and cations
  - Minor anions and cations
  - Organic compounds
  - colloids
- pH and Eh

(Credit: P. Pinedo, Ciemat, Spain)

Working systematically through these lists allows the main features of the biosphere system to be described, alongside the reasons for the various choices. For example, consideration of the socio-economic context of the local human community allows the description of human activities leading to potential radiological exposures (shown for water bodies in Table 2). When all the Principal Component Types have been dealt with, if the assessment context requires it, the inter-relationships between the various Principal Component Types are then described.

The outputs of this stage of the methodology consist of (1) a description (a 'word picture') of the system that describes how the system components are arranged spatially and temporally, and how they interrelate; and (2) a description of the potential exposure pathways.

Simplify word picture of an agricultural system (Credit: P. Pinedo, Ciemat, Spain)



Candidate critical groups

During the Biosphere System Description stage, consideration of the interactions between the biosphere system and the associated human community allows a wide range of potential radiological exposure pathways to be described. Table 2, for example, is part of a table produced as an aid to the methodology. It deals with human activities that could lead to potential radiological exposures from contacts with water bodies. The complete table (not reproduced here) also allows consideration of contacts with the atmosphere, geological media, soils, sediments, fauna and plants. It also lists the parameters for which data will be required.

This information then serves as a basis for the identification of candidate critical groups to which may be added any other potential exposure groups that might be of interest. The methodology also provides detailed guidance on issues such as what is meant by a 'cautious' (as opposed to an 'equitable') approach and how one might address the issue of age-related effects.

Principal Components	Potential exposure mode—Exposure routes	Related activities
Water Bodies	Inhalation: Spray, Aerosols, Volatile	Irrigation, Surface waters, showering, sauna, cooking
	Ingestion: drinking	Drinking
	Ingestion: Incidental Ingestion	During bathing/swimming
	Ingestion: Eating	Cooking practices
	External: Submersion in Water, External from water bodies	Bathing, swimming, ..etc
	Dermal Absorption: Submersion in water	Swimming, bathing, interception of irrigation spray

Human activities leading to potential radiation exposures from contact with water bodies (Credit: BIOMASS Theme 1, IAEA)

The BIOMASS methodology for deriving Reference Biospheres (III)

Model development, data selection and calculation

Model development begins with the construction of a conceptual model, which requires the identification of the relevant 'conceptual model objects': these are distinct environmental media that may influence the dose to the candidate critical groups. These should become evident from screening the 'human activities' table, part of which is shown in Table 2. Examples of conceptual model objects might be soil, water, crops, livestock, but also less obvious items such as a water or crop storage system. The next step is to consider the interactions between the conceptual model objects. Here, an interaction matrix has been found useful and Table 3 shows such a matrix relevant to BIOMASS Example Reference Biosphere 2A, an agricultural system in which contaminated water is used for irrigation (the matrix has been simplified for reproduction here). The conceptual model objects appear in the shaded boxes (generally known as as the leading diagonal elements of the matrix) and the interactions are shown in the un-shaded boxes (the off-diagonal elements). Further explanation is provided in the Table caption.

At this stage it is useful to check the conceptual model against the International FEPs (features, events and processes) List to ensure that no important FEPs have been excluded from the conceptual model.

The next step is to construct a mathematical model to quantify the relationships contained in the conceptual model and there may be a number of alternative mathematical models for any one conceptual model. Compartment models are familiar tools for implementing a mathematical model of radionuclide transport in the biosphere and here one would expect that, put at its simplest, the conceptual model objects would correspond to the model compartments while the off-diagonal elements in Table 3 would correspond to the transfer factors between the compartments. The exposure model would incorporate the candidate critical groups and, indeed, any other potential exposure group that was of interest.

The availability of appropriate data to use in the model is clearly of great importance since the data will directly affect the numerical outcome. Less often appreciated is the fact that data availability will also affect the choice of mathematical model. For these reasons data selection is seen as an important activity within the methodology. Experience with BIOMASS showed that data selection, if carried out with due rigour, puts high demands on expert resources. The combination of data and mathematical model allows the calculation, first of the radionuclide concentrations in the media of interest and second, of the doses (or other endpoints) resulting from exposure of the candidate critical groups to these media. The candidate critical group with the highest dose would be the hypothetical critical group. Almost inevitably, there will be a need for some iteration to ensure that there are no other potentially exposed groups that might receive higher doses than the hypothetical critical group. This might entail additional calculations ('side calculations') that, while they do not affect the calculated doses, provide confidence that the calculations are robust.

Simplified radionuclide transfer matrix for an agricultural irrigation

1	2	3	4	5	6
Water abstracted from aquifer	Irrigation and sediment transfer	Irrigation / leaf interception	Water and sediment ingestion	x	Water and sediment ingestion
x	**Cultivated soil**	Root uptake Soil splash	Consumption of soil on fodder crops	Transfer of soil on crops	Ingestion
x	Weathering Leaf litter	**Food and fodder crops**	Ingestion of fodder	Harvesting	x
x	Manuring	x	**Farm animals**	Slaughtering, milking and egg collection	x
x	Green manuring / composting	x	Consumption of stored fodder	**Farm product storage, distribution & processing**	Ingestion
x	x	x	x	x	**Human community**

The leading diagonal (shaded) elements show the contaminated media (the conceptual model objects) and the off-diagonal elements show the pathways between them. The matrix always works in a clockwise direction so that, for instance, radionuclides in the 'water abstracted from aquifer' (element 1,1) transfer directly to 'food and fodder crops' (element 3,3) via 'irrigation / leaf interception' (element 3,1). Similarly radionuclides in 'farm animals' (4,4) find their way into 'cultivated soil' (2,2) via 'manuring' (2,4). Each of the matrix elements can be related to a component or a feature of the mathematical model. 'x' signifies no radionuclide transfer in the conceptual model.

Credit: BIOMASS Theme 1, IAEA

BIOMASS example Reference Biospheres

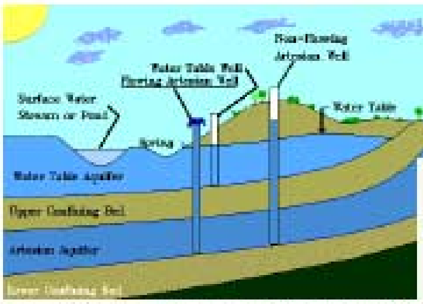
Development of the Examples

If a reference biosphere is to be useful, it clearly needs to be capable of being used in a wide range of circumstances. The most widely applicable assessment biosphere in common use is, perhaps, a drinking water well intruding into a contaminated aquifer. Unfortunately, this suffers from the disadvantage that the range of exposure pathways is narrow, so raising the possibility that potentially important exposure pathways and, indeed, important FEPs might be omitted. A more complex biosphere would allow these complexities to be included but might then become less widely applicable. In devising a practical reference biosphere therefore, the problem is to find an appropriate balance between simplicity and complexity. Within the BIOMASS project, this problem was addressed by developing a range of BIOMASS Example Reference Biospheres ('Examples') of increasing complexity. By taking these through to a numerical calculation it was hoped that it might be possible to make a judgement regarding both the benefits and disbenefits of the additional complexity.

Four Examples were taken all the way through to a numerical calculation. All of them relate to a *temperate climate* though with no specific location in mind; all four assume unchanging biosphere conditions:

(a) Example 1A: a drinking water well intruding into an aquifer that is contaminated with a specified concentration of radionuclides.

(b) Example 1B: a drinking water well intruding into a aquifer that is contaminated by radionuclides and where the radionuclides are released into the aquifer at a specified rate.



DRINKING WATER REFERENCE BIOSPHERE

In many cases, it is desired to have a very simple biosphere model that is still a relevant indicator of repository performance. Such models can be useful in early repository development stages such us proof of concept and site selection, where pertinent site specific data may be lacking. They may be useful in intercomparisons between strategic alternatives for siting or repository design

(c) Example 2A: an agricultural irrigation well intruding into an aquifer that is contaminated with a specified concentration of radionuclides.

(d) Example 2B: a natural discharge from a contaminated aquifer (specified concentration of radionuclides) into a number of different habitats, including arable, pasture, semi-natural wetland and lake.

While the Examples have been used to develop the BIOMASS methodology, they also serve to demonstrate its application. In taking these Examples right through to the point of deriving numerical endpoints, the intention was to fully exercise the methodology, including the issue of data selection. It was this aspect that demonstrated that data selection requires high levels of expert resources. Indeed, the project greatly underestimated the level of effort that would be required to satisfactorily complete the work of data selection and, as a result, it became necessary to restrict Examples 2A and 2B to a relatively narrow range of radionuclides (Nb-94, Tc-99, I-129 and Np-237).

The project also developed the methodology to allow changing biosphere conditions to be addressed and three 'changing biosphere' cases have been taken through to the 'biosphere identification and justification' stage:

(a) A case based on Äspö (Sweden) incorporating biosphere change induced by land rise due to glacial rebound and different, non-sequential, global climate states.

(b) A case based on Harwell (UK) incorporating biosphere change induced by different, non-sequential, global climate states.

(c) A case based on Example 2A with biosphere change induced by different, sequential and non-sequential, global climate states.

BIOMASS example Reference Biospheres (II)

Numerical Outputs from the Examples

As intended, the Examples displayed significant differences, particularly with respect to the radionuclide transfer pathways, the exposure pathways, and the characteristics of the hypothetical critical groups.

Calculations were carried out for Examples 1A and 1B ('drinking water well' pathway) for a wide range of radionuclides. Calculated dose values for the different radionuclides spanned five orders of magnitude, reflecting their different radiotoxicities. The results for Example 1B highlighted the influence of dilution processes at the geosphere-biosphere interface.

For Examples 2A and 2B, results were determined assuming unit concentrations of four radionuclides in groundwater: I-129, Np-237, Tc-99 and Nb-94. These four radionuclides were chosen to demonstrate a range of chemical and biological properties and to be relevant to the disposal of high-level radioactive waste. Doses from the first three radionuclides were dominated by ingestion whereas for Nb-94 (a penetrating gamma emitter) external exposure dominated. A comparison of the calculated doses to the candidate critical groups from these four radionuclides in Examples 1A, 2A and 2B revealed that:

Reactor Nuclear en fase de desmantelamiento

- Ingestion exposures from irrigated agricultural land (Example 2A) were about five times higher than from drinking water alone (Example 1A); for Nb-94 the external irradiation doses were very much higher than those due to ingestion. This led to the conclusion that consideration of the drinking water pathway alone may result in underestimation of the doses to the hypothetical critical group.
- For the four radionuclides examined, ingestion exposures for the natural discharge Example (2B) were up to two orders of magnitude less than those for the irrigated agricultural land Example (2A), provided that consumption of 'wild' (i.e. undomesticated and uncultivated) foods were excluded from Example 2B.
- Radiation exposures due to the ingestion of wild foods have the potential to dominate doses in Example 2B, the natural discharge case. In part at least, this may be because lack of data (on technetium uptake into fungi for example) made it necessary to adopt a cautious approach.
- In broad terms, the data requirements for Example 2B were one to two orders of magnitude greater than for Example 2A, which in turn, were one to two orders of magnitude greater than for Example 1A. At the same time Example 2A generally produced higher doses than 2B, or broadly similar doses if wild foods are included in 2B. This suggests that Example 2B may be approaching the upper limit of what is desirable in terms of complexity.

CONCLUSIONS

Over a four year period, the BIOMASS Theme 1 project has utilised expertise from all over the world to develop a methodology for the logical and defensible construction of 'assessment biospheres': mathematical representations of biospheres used in the total system performance assessment of radioactive waste disposal.

	CONCLUSION's SUMMARY ABOUT THE METHODOLOGY
1	A methodology has been presented for the development of 'assessment biospheres' for use in the safety assessment of solid radioactive waste disposal. An assessment biosphere is defined as :'*the set of assumptions and hypotheses that it is necessary to provide a consistent basis for the calculations of the radiological impact arising from long-term releases of repository derived radionuclides into the biospheres.*'
2	The methodology has been developed to be practical and to be consistent with recommendations from the International Commission on Radiological Protection on radiation protection and disposal of long-lived solid radioactive wastes
3	The methodology was developed involving consultation and collaboration with many relevant organisations, including regulators, operators and a variety of independent experts.
4	The main steps in the methodology are:
	1. development and confirmation of the assessment context;
	2. biosphere system identification and justification;
	3. biosphere system description;
	4. identification of representative exposed population groups, including hypothetical criticagroups;
	5. conceptual and mathematical model development for radionuclide migration and accumulation, and consequent radiation exposures;
	6. calculation of assessment endpoints (e.g. doses) and confirmation, normally by iteration, of the characteristics of the hypothetical critical groups.
5	The importance of a clear assessment context, to clarify intentions and support a coherent biosphere assessment process within the overall repository performance assessment is strongly emphasised. A well described assessment context is an important tool for ensuring a consistency across the performance assessment as a whole
6	The BIOMASS methodology provides a systematic approach to decision making, including decisions on how to address biosphere change.
7	The use of interaction matrices has been found to be helpful in clarifying the interactions between different habitats within the biosphere system and the significant radionuclide transfer pathways within the biosphere system; also as a means of checking for consistency
8	All biosphere models require data and this requirement increases steeply as the models become more complex. A data protocol has been constructed to provide a logical framework for data selection and to promote adequate documentation of this important area
9	Development of the BIOMASS methodology has been focussed primarily on consideration of human radiation exposures derived from groundwater contamination. The methodology is thought to be suitable for other calculational endpoints and source terms. It is also likely that the same key steps in the methodology could be applied to development of reference assumptions for exposures arising through human intrusion.

Credit: BIMASS Theme1, IAEA

CONCLUSIONS (II)

The methodology has been used to create a series of reference biospheres: the BIOMASS Example Reference Biospheres. These are stylised assessment biospheres that, in addition to illustrating the methodology, are intended to be useful assessment tools in their own right. These Examples include numerical calculations, some of which, given an appropriate assessment context, could be used to calculate dose directly from radionuclide concentrations in groundwater. The Examples may also be useful to other assessments by, for instance, indicating the possible level of significance of potentially relevant features, events and processes.

	CONCLUSION's SUMMARY ABOUT THE REFERENCE BIOSPHRE EXAMPLES	
1	The methodology has been developed and demonstrated through the construction of a set of examples. The set of examples involves increasing complexity, demonstrating the implications for biosphere modeling of including a wider range of habitats and groundwater interfaces within the biosphere, and the corresponding increase in the number of radionuclide transfer and exposure pathways.	
2	The set of example assessment contexts was chosen to be as widely relevant as possible, taking into account diverse regulatory requirements and the interests of different assessment groups. These examples are:	
	Example 1A	a simple **drinking water** well under constant biosphere conditions with unit concentration in the aquifer;
	Example 1B	a simple **drinking water** well under constant biosphere conditions with unit release rate to the aquifer;
	Example 2A	an **agricultural well** under constant biosphere conditions with unit concentration in the aquifer;
	Example 2B	**natural groundwater release into agricultural and semi-natural environments** under constant biosphere conditions and with unit concentration in the aquifer;
	Example 3	trial applications of the BIOMASS methodology for the consideration of **biosphere change.**
3	The results have been used to explore the extent to which internationally defined and agreed assessment biospheres might be viewed as points of reference, ie. Reference biospheres. Such reference biospheres could then be used, in combination with other assessment results for the near field and geosphere, for comparing (for instance) the levels of safety provided by different disposal concepts. It is concluded that:	
	• Example 1, 2A and 2B provide generically applicable conceptual and mathematical models that would allow all of them to be used as reference biospheres for radionuclide releases occurring via groundwater, at least for those assessments that have corresponding assessment contexts.	
	• For examples 1 and 2A, where the geosphere-biosphere interface is simple, it is possible to go further. Here it is considered that the numerical results provided are sufficiently well justified to allow their use as indicators of potential radiological impact.	
	• The numerical results from Example 2B would be similarly applicable provided that the geosphere-biosphere interfaces used in the Example are appropriate to the system under consideration.	
4	The examples provide important information on other issues pertaining to radionuclide transfer and exposure pathways:	
	• the significance of release to the biosphere via well abstraction compared to releases from varous natural groundwater flow paths;	
	• the significance of semi-natural habitats compared to agricultural habitats, as well as radionuclide transfers between habitats and associated radiation exposure pathways;	
	• the importance of radionuclide properties in determining critical exposure pathways and dose;	
	• the relative significance of alternative assumptions for exposure groups in a wide variety of exposure circumstances.	
5	The trial examples (Example 3) designed to address issues related to biosphere system change. By reference to two site specific cases and one generic case, Example 3 demonstrates the use of the methodology when (a) land elevation due to glacial rebound and (b) global climate are drivers for biosphere change. The methodology helps to identify the initial conditions and the types of biosphere system and time periods likely to be important. In all three Examples, the the effects of climate change are addressed through consideration of discrete , unconnected biosphere states. The issue of biosphere change is not explored quantitatively however.	

Credit: BIOMASS Theme 1, IAEA

The International Peer Review of the Biosphere Modelling Programme of the US Department of Energy's Yucca Mountain Site Characterization Project

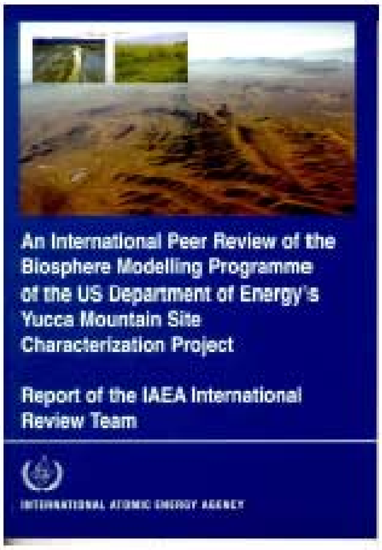
The United States Department of Energy (DOE) has aproject for characterizing the site of a facility for disposing of radioactive waste located at Yucca Mountain, Nevada, USA (the Yucca Mountain Site Characterization Project). This Project has developed an approach for assessing the future potential impact of any releases of radionuclides to the biosphere from a potential disposal facility sited at Yucca Mountain.

The DOE requested the International Atomic Energy Agency (IAEA) to organize an independent international expert review of the assessment methodology being used in its biosphere modelling programme. The IAEA accepted the request in the context of its statutory obligation to provide for the application of its established international standards of safety for the protection of health, at the request of a state, to any of that Sytate's activities in the field of atomic energy.

The terms of reference of the peer review were to review the biosphere assessment methodology being used for the total system performance assessment of the potential disposal facility.

The main purpose was to analyze critically the proposed rationale and methodology and to identify consistencies and inconsistencies between methods being used in the frame of the project and those established in international standards or in international programmes such us the IAEA's Biosphere Modelling and Assessment Programme (BIOMASS)

The review was carried out between September 2000 and January 2001 with the most intensive work taking place during a one-week meeting in Las Vegas at the end of November 2000. The review included examination of DOE contractor documents, presentations of the work by the DOE at which the IRT was able to question DOE and contractor staff, a visit by the IRT to the Yucca Mountain and Amargosa Valley region, and closed discussion meetings of the IRT. Representatives of local stakeholder groups attended both the presentations by the DOE and also a close-out meeting at which the Chairman of the IRT made an oral presentation of preliminary observations and recommendations of the review to DOE representatives and observers.



The International Review Team (IRT) assembled by the IAEA consisted of six members from national advisory bodies, waste management organizations and regulatory bodies, plus a representative of the IAEA and a consultant to assist in documenting the review. *(Credit: A. van Luik, USA)*

The objective of the peer review is to provide, on the basis of available international standards and guidance, an independent evaluation of the biosphere assessment methodology developed by the US DOE's Yucca Mountain Site Characterization Project.

The main input documentation for the review was the "Biosphere Process Model Report" (PMR) and its sixteen supporting "Analysis and Model Reports (AMRs). In addition, the IRT selectively examined a number of documents as background to the review, including the proposed regulations appliucable to the Yucca Mountain facility.

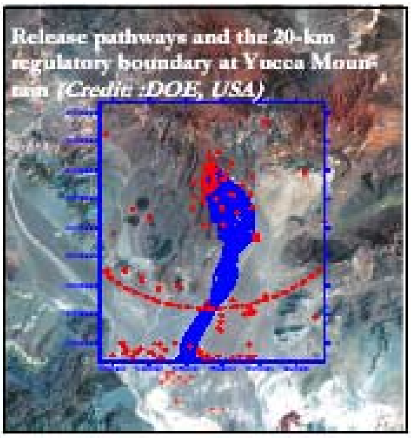
In particular attention was drawn to:

- **Publications from the International Commission on Radiological Protection (ICRP),.**
- **The IAEA BIOMASS programme, which has developed a methodology for the construction of biosphere models for long–term safety assessment and also provided worked examples of the application of the methodology**

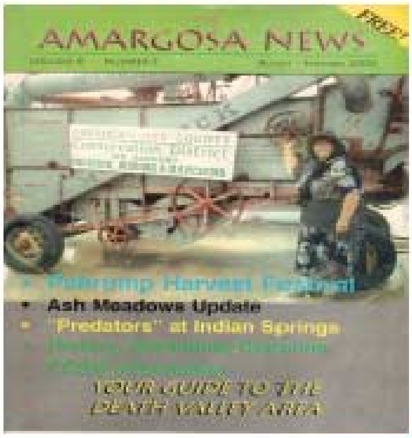
The International Peer Review of the Biosphere Modelling Programme of the US Department of Energy's Yucca Mountain Site Characterization Project

The review work included a visit by to the Yucca Mountain site and Amargosa Valley region. The team made a one day vist with DOE and contractor staff. The experts had the opportunity to study the proposed repository site and its surroundings including the location near the junction of the US Route 95 and Nevada route 373 identified in the EPA and NRC proposed rules, the Amargosa Valley including its farmlands, the Amargosa River and Franklin Lake Playa.

YMD-060500-2 Panoramic view of Crater Flat from Yucca Crest.



Release pathways and the 20-km regulatory boundary at Yucca Mountain (Credit :DOE, USA)



YUCCA MOUNTAIN PRESENT BIOSPHERE (Credit: : A. Van Luik, DOE, USA)

The International Peer Review of the Biosphere Modeling Programme of the US Department of Energy's Yucca Mountain Site Characterization Project

RECOMMENDATIONS AND SUGGESTION's SUMMARY	
For improvements to the biosphere assessment capability while remaining focused on satisfying the regulatory requirements	
1	The DOE should, in future, consider more fully the possible aims of biosphere assessment within the Yucca Mountain Site Characterization Project both within and outside the regulatory framework. Possible expanded aims might be:
2	• To identify and investigate the role of environmental, including site-specific, processes that may be relevant to the environmental accumulation and distribution of radionuclides in the long-term, uptake into foodstuffs
3	• To investigate a range of potential exposure scenarios and circumstances in order to support arguments for the adequacy of exposure scenarios defined by regulation, or identify alternative or supplementary exposure scenarios.
4	The consideration of the biosphere should be in the future more fully integrated into the total system conceptual model
5	The DOE should consider a programme of biosphere characterization including on-site measurements
6	Regarding the diet and habits that should be assigned to the critical group for compliance assessment, the review team considers that the DOE has placed too great a significance on habits determined from the 1997 survey. The team recommends that it would be prudent for the DOE to consider all human activities that might reasonably and consistently occur and to consider cautious but not extreme dietary intakes and exposure times. The 1997 survey is one input to this consid-
7	The DOE should consider how best to capture and use the existing scientific and local knowledge regarding the biosphere
8	The DOE should examine the methods of conceptual model construction described, for example, in the BIOMASS documentation and in national assessment studies, with a view to devising a method that more clearly tracks the incorporation of individual FEPs into the biosphere model
9	The consistency of the parameters with the assumptions made in the biosphere model as well as with the site-specific conditions found in Amargosa Valley should be considered and discussed in more detail.
For activities outside the regulatory requirements	
1	It would be prudent for the DOE to satisfy itself that the constraints imposed for compliance assessment do not lead to the neglect of potentially significant uncertainties, processes and interactions that might be considered in a wider context, including a fuller safety assessment
2	A sufficiently broad examination of possible release pathways and related exposure situations should be examined to identify and justify the more closely-defined case adopted for compliance demonstration, and that
3	Logical extensions of the compliance case and alternative or supplementary situations should be considered to place the case in perspective and to assess the level of bias against a broader spectrum of possible cases.
4	The DOE should identify and evaluate a range of alternative and supplementary biosphere scenarios
5	The DOE should continue to estimate performance for times beyond the time frame required for regulatory compliance.
6	The DOE could present in the longer time frame a number of complementary performance indicators that are less dependent on the assumptions concerning human habits.
7	The DOE should look for opportunities to obtain field data that would enable some degree of model testing, or otherwise support the model

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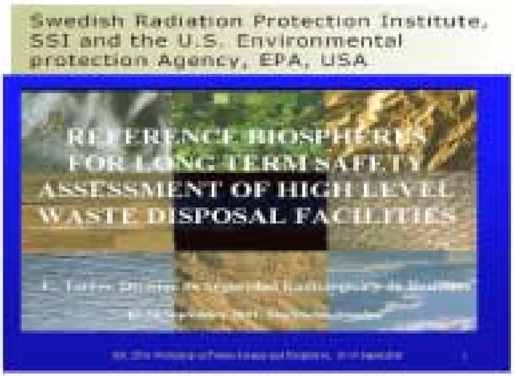

Speaker's summary

Mr. Torres-Vidal has 18 years experience as a Nuclear Environmental Scientist with a good background and knowledge of environmental modelling and monitoring, radiation protection and waste safety. Mr. Torres-Vidal was born on 9th of August 1960 in Cordoba, Spain. He was educated at the Polytechnic University of Madrid in Spain, where he became an Industrial Engineer specialist in Nuclear Engineering in **1983**.

Carlos Torres-Vidal joined the *International Atomic Energy Agency (IAEA)* as a Nuclear Environmental Scientist in **August 1995**. He has been the *Head of the Radiation Protection of the Public and the Environment Unit*, which is part of the Department of Nuclear Safety, since **August 1999**. The Unit's main function is the establishment of safety standards for the control of radioactive discharges to the environment. The Unit is engaged in establishing standards for the protection of the environment and in providing advice and guidance on procedures and methods for environmental assessment, modelling and monitoring. The Unit is the focal point for the IAEA's technical interactions with international conventions and treaties concerned with radioactive waste and the environment. Since joining the IAEA in 1995, he has co-ordinated the IAEA project on Biosphere Modelling and Assessment (BIOMASS) and acted as Scientific Secretary of the Co-ordinated Research Programme on IMprovement of Safety Assessment Methodologies for Near Surface Waste Disposal Facilities (ISAM). He has also organized international meetings and prepared technical documents related to environmental modelling and monitoring, safety assessment and waste acceptance criteria for waste disposal facilities. He has managed international projects and organized training events on radiation protection and radioactive waste management in Argentina, Brasil, Chile, Colombia, Cuba, Mexico, Paraguay, Uruguay, Venezuela, Eastern European countries and Former Soviet Union republics, in conjunction with the IAEA's Department of Technical Co-operation.

Mr. Torres-Vidal is member of several advisory groups within the OECD/NEA and IAEA. He has lectured physics and mathematics at the Polytechnic University of Madrid and at courses organized by Spanish and international organizations on waste safety, radiation protection, environmental modelling, monitoring and safety assessment of nuclear power plants and waste disposal facilities.

THE EC BIOCLIM PROJECT (2000-2003) 5TH EURATOM FRAMEWORK PROGRAMME- MODELLING SEQUENTIAL BIOSPHERE SYSTEMS UNDER CLIMATE CHANGE FOR RADIOACTIVE WASTE DISPOSAL -

M. Calvez
ANDRA, France

The BIOCLIM Project in Brief

The BIOCLIM project on modelling sequential BIOsphere systems under CLIMate change for radioactive waste disposal is part of the EURATOM fifth European framework programme. The project was launched in October 2000 for a three-year period. The project aims at providing a scientific basis and practical methodology for assessing the possible long term impacts on the safety of radioactive waste repositories in deep formations due to climate and environmental change.

Two complementary strategies (hierarchical/discrete and integrated/continuous) will provide representations of future climate changes for periods of up to the next million years. Global climate results will be downscaled to derive regional/local climates. Climate and vegetation will be simulated for various European areas. These results will be used to derive an understanding of the environments (i.e. the biosphere systems) through which radionuclides may migrate and lead to potential exposure of Man. Finally, these exposure and migration pathways will be described for selected biosphere systems using two different approaches: a discrete set of snapshots, as has typically been used in assessments to date, and a more innovative, continuous representation.

The project has the following objectives:

- To develop two practical and innovative strategies for representing climate changes in biosphere systems for regions in Europe (Central/Southern Spain, Northeast France, Central England);

- To explore and evaluate the potential effects of climate change on the nature of the biosphere systems used to assess the environmental impact;

- To disseminate information on the new methodologies and the results obtained from the three year research project among the international waste management community for use in performance assessments (PAs) of potential or planned radioactive waste repositories.

The final outcome will be an enhancement of the state-of-the-art treatment of biosphere system change over long periods of time through use of a number of innovative climate modelling approaches and the application of the climate model outputs in PAs.

The project is co-ordinated by ANDRA, Agence Nationale pour la Gestion des Déchets Radioactifs (France) and brings together a number of representatives from both European radioactive waste management organisations which have national responsibilities for the safe disposal of radioactive waste, either as disposers or regulators, and several highly experienced climate research teams (CEA/LSCE, NIREX, GRS, ENRESA, CIEMAT, UPM-ETSIMM, NRI, UCL/ASTR, EA, UEA, ENVIROS QuantiSci).

BACKGROUND

The project has been initiated on the basis of the requirements of European waste management agencies to assess the feasibility and safety of radioactive waste repositories in geological formations, with regard to possible long-term impacts due to climate change. In addition to climate, the associated biosphere system may be subject to major change. Predictions over one million years cannot be considered as very reliable, however possible future evolution scenarios can be proposed, based on the past history of the climate system. Collaboration within the project by participants with different types of expertise will provide a robust scientific basis and practical results to demonstrate how climate and related environmental changes can be represented in radiological PAs.

Work Packages

The project is designed to advance the state-of-the-art of biosphere modelling for use in PAs via five work packages (WP).

3.1. WP 1 – Consolidation of the needs

The requirements of the European waste management agencies of the consortium will be consolidated and the current methods used to represent environmental change will be summarised by:

- Identifying the mechanisms and processes that cause long-term climate change and the environmental consequences of such changes;
- Describing available palaeo-environmental data for the European regions of interest for further use in the future climate simulations.

3.2. WP 2 – Hierarchical strategy

A hierarchy of climate models (Earth system Model of Intermediate Complexity, General Circulation Model and regional climate model) will be used to derive the environmental changes for selected discrete climatic situations (e.g. glacial and interglacial). Results will consist in climate and vegetation cover. Downscaling approaches will be developed and evaluated.

3.3. WP 3 – Integrated strategy

This strategy consists of building an integrated, dynamic climate model, representing all the mechanisms important for long-term climatic variations. The time-dependent results will be interpreted in terms of regional climate as well as vegetation changes using downscaling approaches.

3.4. WP 4 – Biosphere system description

The output from the climate models developed in WP 2 and 3 will be interpreted in terms of requirements of PA models, and in order to demonstrate how biosphere systems can be represented in the long-term. In particular, innovative guidance will be provided to represent a transitional biosphere system.

3.5. WP 5 – Final seminar

The methodologies and results obtained from the three-year project will be disseminated within the international scientific/technical and waste management community for further use. All deliverables will be made publicly during the course of the project and a final seminar will be organised in October 2003.

Results

Several deliverables (D) will be produced among the five work packages (see table 1). As soon as finalised, they will be available on the BIOCLIM web site.

Table 1**. List of deliverables**

WP 1	– Mechanisms causing long-term climate change and environmental consequences. Summary of the methods currently used in PAs and lessons learned in their application (D1); – Narrative descriptions and summaries of palaeo data for the European regions of interest (D2).
WP 2	– Selection and justification of global climate scenarios for periods up to one million years (D3); – Global and European regional climate characteristics, output from discrete climate models at specific selected times (D4); – Global and European regional vegetation characteristics at specific selected times (D5); – Climate and vegetation characteristics for three regions within Western Europe derived using downscaling approach (D6).
WP 3	– Scenarios for continuous climate evolution for one hundred thousand years or longer for Western Europe (D7); – Comparison of regional climate characteristics using downscaling approaches (D8); – Vegetation for the time scales of interest for the three regions within Western Europe (D9).
WP 4	Approach to the application of long-term climate model outputs to discrete biosphere systems for the three regions and the time scales of interest (D10); Methodology for addressing transitional biosphere systems (D11); – Reference biosphere system descriptions using discrete and transitional methods and approaches for developing relevant conceptual models for use in PAs (D12).
WP 5	– Proceedings of the final seminar, including results from climate model developments and the application of the different methods developed during the project for use in radiological PAs (D13).

Meetings

Ten project meetings are scheduled to promote efficient information exchange within the consortium. The presentation of final results to the European Commission and a wider international audience will take place during the final seminar in October 2003.

HIGHLIGHTS AND COMMENTS FROM A REGULATORS' WORKSHOP

Presented at the IGSC Meeting, 24-26 October 2001.

M Jensen

SSI, Sweden

1 Introduction

The programs for final disposal for high-level radioactive waste have come to a mature state in many countries. Technical information available to support decisions varies in time and from stage to stage. There is a strong trend for all waste management institutions to address issues related to stakeholder confidence. Technical expertise and confidence have been shown to be insufficient, on their own, to justify to the general public that geologic disposal is the appropriate waste management solution. SSI and EPA have acknowledged this by co-hosting a conference in Stockholm during 1998 involving technical issues and stakeholder communication.

However, there are still a number of mainly technical and scientific questions remaining, related to compliance assessments for geological repositories, for which it is widely recognised that a common view among regulators would facilitate the understanding of performance assessment internationally. Some of these are related to the role of the biosphere and the society in demonstrating compliance. There is no international consensus in this area, yet it is obvious that these issues will gain even more attention in the future, when compliance issues are discussed in the licensing proceedings.

For the above reasons, SSI and US EPA arranged a workshop 11-13 September 2001, in Stockholm, titled "The Role of Future Society and Biosphere in Demonstrating Compliance with High-level Radioactive Waste Disposal Standards and Regulations".

The workshop brought together experts from 8 regulatory agencies in 6 countries (USA, UK, Sweden, Finland, Norway, Belgium and Lithuania) and from 2 international bodies (IAEA and ICRP).

The views expressed below are those of the author. SSI and EPA will shortly publish a formal report.

2 IAEA

Carlos Torres, IAEA, presented the BIOMASS Theme 1 output. A presentation of this item is scheduled for the OECD/NEA Integration Group for the Safety Case meeting 24-26 October 2001, and should be available at the meeting.

IAEA's further work in this area was discussed. Several participants took the view that a safety document, a specific level of IAEA documents, would be useful, because several countries are in process of making decisions on repositories. The status of the existing guidance could be usefully upgraded.

3 ICRP

The International Commission on Radiological Protection (ICRP) has recently made a contribution in the area of post-closure requirements by its recommendations in ICRP Publication 81. The publication contains guidance regarding risk or dose levels relevant for, although not directed exclusively to, geological disposal of high-level radioactive waste and spent nuclear fuel. Work is in progress within various international bodies about the possible response to the views presented in this document.

Jack Valentin, secretary to the Commission, presented some new activities and explained some of the Commission’s views.

Environmental Protection

The Commission has started work on environmental protection and created a task group "on Protection of the Environment". Earlier, ICRP has stated that where adequate provisions are in place to protect man, then also the environment is protected. While this is still true for a large range of scenarios, some exist where the environment needs separate consideration.

Protection from intrusion

ICRP is not directly concerned with protection of society from consequences of actions by advertent intrusions. Also, no advice has been given the safeguards issues. Inadvertent intrusion is mentioned in ICRP 81.

Collective dose

This concept is a topic of many discussions today, also within ICRP. It is regarded as a useful concept in ICRP 81.

New trend on personal protection

Generally, there is a trend in society towards individual protection with optimisation coming second. Perhaps new recommendations will reflect such a re-focus. On it’s own this switch does not change things, but also the optimisation process will also change.

Optimisation

Optimisation is thought to include a large range of activities. Rather than consulting a formula for collective dose reduction in terms of cost, the process of optimisation is related to a broad range of activities to minimise doses. For geological repositories it also contains ideas of stakeholder consultation. The word reasonably in the formulation “as low as reasonably achievable” should be included to imply that “people should tell us what is reasonable”.

STUK's Approach to Biosphere Description

The Finnish recent regulations presented by Kirsti-Liisa Sjöblom was based on a paper by Esko Ruokola to the IAEA Specialist Meeting in Vienna, 18-22 June, 2001, some of which is quoted below.

A regulatory guide for the safety of spent fuel disposal has recently been issued in Finland to guide the implementer's programme in the pre-construction phase. The guide is based on dose criteria in the nearest time era. That is defined as the time frame " which is reasonably predictable with respect to assessment of human exposure". For the later time frame that involves major climate changes such as permafrost and glaciation, the guide defines constraints for the activity releases to the environment.

The Government's general safety regulation includes the following the radiation protection criteria:

> *In an assessment period that is adequately predictable with respect to assessments of human exposure but that shall be extended to at least several thousands of years.*
>
> *(1) the annual effective dose to the most exposed members of the public shall remain below 0.1 mSv, and*
>
> *(2) the average annual effective doses to other members of the public shall remain insignificantly low.*
>
> *Beyond the assessment period referred to above, the average quantities of radioactive substances over long time periods, released from the disposed waste and migrated to the environment, shall remain below the nuclide specific constraints defined by the Radiation and Nuclear Safety Authority. These constraints shall be defined so that.*
>
> *(1) at their maximum, the radiation impacts arising from disposal can be comparable to those arising from natural radioactive substances, and*
>
> *(2) on a large scale, the radiation impacts remain insignificantly low.*

The Finnish government's approach includes a proscriptive treatment of the last era, so that the authority, STUK, after calculation based on different scenarios, defines the maximum acceptable release rate from the repository.

The approach implies that the regulator takes some burden of responsibility for the description - or lack of description - of the distant future.

The concept was discussed and the regulatory requirements for the distant future were discussed among the workshop participants.

Sustainable development

The author of this paper introduced the issue of sustainable development (2). The main idea behind this is a re-definition of the goal, to describe it not as a dose definition coupled to a need for prediction, but in terms of allowing future societies a large range of activities within a large range of possible environments. This formulation is close to the formulation used by the Bruntland

Commission (3), “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs”*.

The discussion showed a range of opinions on this issue, from the view that the approach was true but more or less self-evident. To a more careful position from which it was pointed out that sustainable development is only a part of government policy, and that different mandates for regulators may prevent a complete consensus.

FASSET

Carl Magnus Larsson, SSI, described the FASSET project (Framework for Assessment of Environmental Impact).

The issue of protection of the environment can be seen in various ways, as an anthropocentric wish to preserve a better environment for the benefit of man, or to allocate an intrinsic value to nature, in a view where man is part of nature.

Secondary standards

Rodolfo Avila from SSI suggested that regulators look at secondary standards, and in particular environmental concentrations. In compliance judgements, the standard could consider distributions of concentration rather than a single value.

A benefit of such a standard would be that a standard could cover both man and the environment.

Further work

The participants presented conclusions in two categories. The first category contained general or philosophical issues, such as sustainable development and protection of the natural environment. The definition of the biosphere in the distant future, and the division of responsibility expressed by the Finnish regulation, was also considered further discussion.

The meeting expressed an interest in further work, but also expressed concern that there might be institutional reasons to limit the degree of consensus in these matters.

In the second category, technical work, the issue of the geosphere/biosphere interface was considers one of the most important issues. This issue was also seen contain the balance of the work made to describe the biosphere vs. the available details in the interface.

Conclusions

As many waste programmes come to a mature state, there is increased need for regulators to have good insight in international regulatory work. The fact that regulations are different makes it even more important to know the background for those differences. Within the last few years international regulatory fora in the IAEA and NEA and the CEC has been established and some of the future regulatory co-operation will take place there. The SSI-EPA initiative has showed that bilateral co-operation also can offer effective contribution to this work.

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3. United Nations, 1987

POSIVA'S STRATEGY FOR BIOSPHERE STUDIES

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1 Regulatory Requirements

Regulatory requirements for biosphere analyses are specified in the Government Decision on the Safety of Disposal of Spent Nuclear Fuel (STUK 1999) and, in more detail, in the regulatory Guide YVL 8.4 (STUK 2001).

Dose constraints for several thousands of years

In an assessment period that is adequately predictable with respect to assessments of human exposure but that shall be extended to at least several thousands of years:

- the annual effective dose to the most exposed members of the public shall remain below 0.1 mSv; and
- the average annual effective doses to other members of the public shall remain insignificantly low.

These constraints apply to radiation doses which arise to members of the public as a consequence of expected evolution scenarios and which are reasonably predictable with regard to the changes in the environment. Humans are assumed to be exposed to radioactive substances released from the repository, transported to near-surface groundwater bodies and further to watercourses above ground. At least the following potential exposure pathways shall be considered:

- use of contaminated water as household water;
- use contaminated water for irrigation of plants and for watering animals;
- use of contaminated watercourses and relictions.

Changes in the environment to be considered in applying the dose constraints include at least those arising from land uplift. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to be similar to the current ones.

The constraint for the most exposed individuals, effective dose of 0.1 mSv per year, applies to a self-sustaining family or small village community living in the vicinity of the disposal site, where the highest radiation exposure arises through the pathways discussed above. In the environs of the community, a small lake and a shallow water well is assumed to exist.

In addition, assessment of safety shall address the average effective annual doses to larger groups of people, who are living at a regional lake or at a coastal site and are exposed to the radioactive substances transported into these watercourses. The acceptability of these doses depend on the number of exposed people, but they shall not be more than one hundredth – one tenth of the constraint for the most exposed individuals.

Release rate constraints after several thousands of years

According to the Government Decision, the average quantities of radioactive substances over long time periods released from the disposed waste and migrated to the environment, shall remain below the nuclide specific constraints defined by the Radiation and Nuclear Safety Authority. These constraints shall be defined so that:

- at their maximum, the radiation impacts arising from disposal can be comparable to those arising from natural radioactive substances; and

- on a large scale, the radiation impacts remain insignificantly low.

Guide YVL 8.4 specifies nuclide specific constraints for the activity releases to the environment are as follows:

- 0.03 GBq/a for the long-lived, alpha emitting radium, thorium, protactinium, plutonium, americium and curium isotopes;

- 0.1 GBq/a for the nuclides Se-79, I-129 and Np-237;

- 0.3 GBq/a for the nuclides C-14, Cl-36 and Cs-135 and for the long-lived uranium isotopes;

- 1 GBq/a for Nb-94 and Sn-126;

- 3 GBq/a for the nuclide Tc-99;

- 10 GBq/a for the nuclide Zr-93;

- 30 GBq/a for the nuclide Ni-59;

- 100 GBq/a for the nuclides Pd-107 and Sm-151.

These constraints are based partially on biosphere analyses (e.g. Karlsson & Bergström 2000, where SR 97's biosphere models have been applied on Olkiluoto) and partially on comparisons with natural fluxes of long-lived radionuclides.

These constraints apply to activity releases which arise from the expected evolution scenarios and which may enter the environment not until after several thousands of years. These activity releases can be averaged over 1000 years at the most. The sum of the ratios between the nuclide specific activity releases and the respective constraints shall be less than one.

Consideration of unlikely events

The importance to long-term safety of unlikely disruptive events impairing long-term safety shall be assessed and, whenever practicable, the acceptability of the consequences and expectancies of radiation impacts caused by such events shall be evaluated in relation to the dose and release rate constraints specified above.

The considered unlikely disruptive events shall include at least:

- boring a deep water well at the disposal site;
- core-drilling hitting a waste canister;
- a substantial rock movement occurring in the environs of the repository.

The importance to safety of any such incidental event shall be assessed and whenever practicable, the resulting annual radiation dose or activity release shall be calculated and multiplied by the estimated probability of its occurrence. The expectation value shall be below the radiation dose or activity release constraints. If, however, the resulting individual dose might imply deterministic radiation impacts (dose above 0.5 Sv), the order of magnitude estimate for its annual probability of occurrence shall be 10^{-6} at the most.

Consideration of protection of other living nature

Disposal of spent fuel shall not affect detrimentally to species of fauna and flora. This shall be demonstrated by assessing the typical radiation exposures of land and aquatic populations in the disposal site environment, assuming the present kind of living populations. These exposures shall remain clearly below the levels, which, on the basis of the best available scientific knowledge, would cause decline in biodiversity or other significant detriment to any living population. Moreover, rare animals and plants as well as domestic animals shall not be exposed detrimentally as individuals.

2. Posiva's strategy

Posiva welcomes the regulator's clear and transparent requirements and guidance in the field of biosphere analyses. To fulfil the requirements Posiva will:

- evaluate the evolution at the potential discharge areas at Olkiluoto for the next several thousands of years. Groundwater flow modelling will be used to identify the potential discharge areas. Sea bottom topography and sediments will investigated to take into account the effects of land uplift (presently approx. 6 mm/a at Olkiluoto);
- study circulation and mass transfer processes (physical, chemical, microbiological) of elements;
- to carry out biosphere modelling for potential recipients at Olkiluoto (well, lake, sea, sediment that later will be exposed due to land uplift, forest, peat bog). Development of models is planned to be carried out in co-operation with SKB.

As concerns effects of human actions and consideration of other living nature, Posiva is actively seeking for international co-operation, for example within IAEA, in these new researches fields.

3. Comments on potentially problematic nuclides

C-14

The release rate constraint of C-14 is rather low and is based on the assumed enrichment of inorganic C-14 in the biosphere. However, corrosion of metals in anaerobic conditions may release carbon mainly as methane, which does not retard in anything – but, on the other hand, does not cause significant dose exposures. Fortunately, the release rate of C-14 is limited by the corrosion rate of metals.

Radon and other daughters of Ra-226

Release rates of Rn-222 and other short-lived nuclides may be significantly higher than that of the long-lived parent and depend crucially on conditions close to the geosphere-biosphere interface. Fortunately, there is only a small amount of Ra-226 in the spent fuel initially and for several thousands of years.

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THE BIOSPHERE INTERNATIONAL PEER REVIEW

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The US Department of Energy (DOE) requested the International Atomic Energy Agency (IAEA) to provide, on the basis of available international standards and guidance, an independent evaluation of the biosphere assessment methodology developed by the DOE Yucca Mountain Site Characterization Office (YMSCO). In response, the IAEA assembled a 6-member panel of experts drawing from member nations' national advisory committees, waste management organisations and regulatory bodies. The IAEA also provided a scientific secretary from IAEA, and a panel secretary to document the review.

Panelists were:

- Professor Roger H. Clarke, Panel Chair, Director, National Radiological Protection Board, UK;
- Pedro Carboneras, Head, Safety & Licensing Department, ENRESA Spain;
- Ian Crossland, Strategic Technical Liaison Manager, United Kingdom Nirex Limited, UK;
- Carl-Magnus Larsson, Head, Dept. of Waste Management and Environment, Swedish Radiation Protection Institute (SSI), Sweden;
- Gerhard Pröhl, Sr. Scientist at GSF, National Research Centre for Environment and Health, Institute for Radiation Protection, Germany;
- Hiroyuki Umeki, General Manager, Nuclear Cycle Backend Division, Japan Nuclear Cycle Institute, Japan;
- Carlos Torres-Vidal, Scientific Secretary, IAEA BIOMASS Project International Atomic Energy Agency, Austria;
- Trevor Sumerling — Panel Secretary, Safety Assessment Management Limited, UK.

The review team examined the Biosphere Process Model Report, its sixteen supporting Analysis and Model Reports (AMRs) and calculations, Environmental Protection Agency and Nuclear Regulatory Commission proposed regulations, and other background documents during August through November 2000.

Question and answer exchanges occurred via email during this same time, and a 1-week site visit was made. During the site visit the review team acquired additional information during interactive presentations from DOE and contractor staff, conducted a site visit to the Yucca Mountain and the Amargosa Valley region, and held closed discussion meetings.

At the conclusion of the site visit, the review team summarised preliminary observations orally to DOE and local stakeholder groups. A draft report was submitted for checking facts only in January of 2001, and a final report was published in April of 2001.

The DOE considered the results of the review favourable, with comment focused primarily on efficiencies and enhancements. Twenty-three recommendations were made that addressed three categories: (a) DOE’s Biosphere Assessment Approach (5), (b) Definition of Biosphere System (7), and (c) Model Development, Data, and Results (11).

Review of the DOE’s biosphere assessment approach included a review of its assessment context. There was recognition of the regulatory basis for the program and of the impact of that basis on the historical process leading to development of integrated TSPA and its biosphere component. It was observed that the Biosphere capability was less mature than the major part of TSPA and perceived as a semi-independent “accessory” to the TSPA. This is in part due to the separation of the biosphere from TSPA by the prescriptive nature of regulations. The regulations remove an incentive to explore other potential exposure and release scenarios.

In that context, the review team recommended that a sufficiently broad examination of possible release pathways and related exposure situations should be examined to identify and justify the more closely defined case adopted for compliance demonstration. Documents that provide logical extensions of the compliance case and alternative or supplementary situations should be created to place the case in perspective and to assess the level of bias against a broader spectrum of possible cases. A DOE response is that evaluation of additional pathways is currently in progress, and other recommended analyses may be pursued later.

The International Review Team recommended that the consideration of the biosphere be more fully integrated into the total system model. This does not imply that a coupled modelling capability is required, rather, that the interactions be more fully considered in the system conceptualisation. DOE’s response is that opportunities for better integration of the biosphere component with the TSPA are currently being investigated.

Specific recommendations were made on biosphere characterisation. For example it is stated that DOE should consider a biosphere characterisation program that includes on-site measurements, and DOE should also consider obtaining site-specific biosphere characteristics and processes related to soil and its potential development.

The DOE response is that the need for site-specific model data will be determined based on the results of the recommended and planned sensitivity analyses. Soil-related parameters will be re-evaluated; additional work will include justification of the site-specificity of the Kd values. This issue has also been raised by the US Nuclear regulatory Commission and further work was agreed to by the DOE as per a written sub-agreement included in the Total System Performance Assessment and Integration (TSPAI) Key Technical Issue (KTI) agreement.

Regarding the diet and habits that should be assigned to a RMEI or critical group for compliance assessment, the reviewers felt that DOE has placed too great significance on habits determined from the 1997 food consumption survey. DOE should consider all human activities that might reasonably and consistently occur but not extreme dietary intakes and exposure times. It was suggested that DOE consider updating the 1997 food consumption survey.

In response, several sensitivity analyses were conducted to determine how annual dose results are affected by the receptor's dietary habits. Results of these analysis allow the consequences of selecting a more conservative receptor to be bounded (the results are likely to be bounded by approximately a factor of three). The 1997 food consumption survey may be supplemented in the future with other available information.

Specific recommendations were made regarding FEPs and conceptual models, such as that DOE should examine the methods of conceptual model construction described, for example, in the BIOMASS documentation and in national assessment studies to devise a method to more clearly track incorporation of individual FEPs into the biosphere model. In response, the DOE is currently comparing the conceptual bases and mathematical representation of the biosphere model with other models. This includes BIOMASS and thus enhancing FEPs identification and tracking (this issue is also identified as needing attention by the US NRC, per a written agreement for additional work by the DOE, described in the TSPA KTI document previously mentioned).

The review team felt that DOE should re-assess the treatment of uncertainties in the biosphere. In particular, DOE should consider the uncertainties that are best represented in the regulatory scenarios within the TSPA, those that are best evaluated in "stand alone" mode, and those best explored through alternative models and scenarios. DOE should also enhance discussion of uncertainties due to the scenario specification, model choice and parametric uncertainties, and explain the limitations of the approach and consequent results.

The DOE response is that model and parametric uncertainties are currently planned to be re-evaluated as a part of the upcoming LA AMR revisions, and that additional uncertainty analyses have been conducted to support SR. Results of these supplementary analyses are documented in the documentation of the Supplemental Science and Performance Analyses (SSPA) Vol. 1, Section 13.

The panel also recommended that analyses to timeframes beyond the regulatory requirement be continued, that food consumption survey(s) similar to the 1997 survey be repeated periodically, and that conditional doses be reported for the volcanic event.

Most of the recommendations received are to be acted on, and are to be included in the License Application plan for biosphere modelling. Some work suggested by the review team has been done since the review was completed, and is reported in the DOE's mid-2001 SSPA publications and subsequent documentation.

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