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NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE

Advisory Group on the Assessment of the Performance of Waste Disposal Systems (PAAG)

THE ROLE OF THE ANALYSIS OF THE BIOSPHERE AND HUMAN BEHAVIOUR IN INTEGRATED PERFORMANCE ASSESSMENTS

A discussion document and proposal, by the NEA Secretariat, in support of Agenda item 14b of PAAG-15.

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The role of the analysis of the biosphere and human behaviour in integrated performance assessments

(a discussion document, and proposal, by the NEA secretariat)

Abstract

When it comes to evaluating safety from waste disposal, it must be recognised that the treatment of uncertainties in the biosphere is particularly problematic because the likely changes in the biosphere will be larger and occur more quickly than in other parts of the system. The situation is not unlike dealing with human actions scenarios, hence stylised biospheres have been suggested along with the use of complementary performance indicators as means to illustrate the safety features of the disposal system. At present, there is not a common understanding of the role of biosphere analysis in safety assessment, at international level. On the other hand, if this understanding exists it appears to be insufficiently documented. It is proposed that these aspects receive renewed attention within the general NEA/RWMC framework, thus continuing the work performed so far by PAAG. The final aim is to provide international input to both programmatic and regulatory decision making in the field of safety assessment. The work that needs to be performed is of different nature, and at more general level, than that carried out in specialist groups dealing with biosphere modelling. Namely, the topic here is the role of the biosphere in integrated total system performance assessment and not R&D activities on the biosphere itself. Several recent developments internationally favour the timely start of a focused initiative. It is thus proposed that the PAAG relates to the Bureau-Chairmen group the importance of the subject of biosphere analysis within safety assessment in the general context of the treatment of uncertainty and confidence building, and that a suggestion be made for an initiative in this area, e.g., with the aim to produce a short report illustrating the relevant experience and principles.

INTRODUCTION

At the international level an important effort is being made to develop reference biospheres to be used for the purpose of safety assessment. Progress is being made thanks to the BIOMASS project. BIOMASS is largely intended to develop the technical bases for producing reference biospheres that are acceptable to scientists dealing with biosphere analysis. One of the issues these scientists face is that some of the processes concerned are inherently unpredictable and different methods may be required to treat the different sources of uncertainty. In solving such issues, logical methods must be applied and the inherent limitations must be recognised and communicated.

When it comes to evaluating safety from waste disposal, biosphere scientists recognise that "*The treatment of uncertainties in the biosphere is particularly different from other parts of the system under assessment because the likely changes in the biosphere will be larger and occur more quickly than in other parts of the system.*" [BIOMASS, THEME 1:WD2 - April 1998].

The role of biosphere representation and analysis - and the attending treatment of its uncertainty - in safety assessments is a topic germane to the programme of work of the Performance Assessment Advisory Group (PAAG) of the NEA which has commented several times on this topic, e.g. see NEA/PAAG/DOC(98)6. Indeed, recent developments within BIOMASS, e.g., the further elaboration and documentation of the well scenario, have occurred partly in response to the concerns raised by the PAAG.

The PAAG has stated in the past that stylised, simple biospheres (termed "benchmark biospheres" in NEA/PAAG/DOC(98)6) should be used in safety assessments and that these should be seen mainly as a means to provide "dose conversion factors" in a situation of potential exposures, as intended in the ICRP framework. Implicit in the PAAG position - and within the international positions suggesting the use of stylised biospheres - is the judgement that the uncertainty in the estimation of future radiological impact that is due to a lack of knowledge over the future state of the biosphere should not form a bar to the development of safe, long-term waste management strategies. Indeed, it has been noted that "*geological disposal is less susceptible to the effects of many uncertainties, especially related to future human actions, than most other options*" [NEA/PAAG/DOC(98)6]. In this respect, the situation is qualitatively similar to that of representation of human intrusion events, in which case the international community accepts the use of stylised scenarios, e.g. see NEA/RWM/DOC(95)8. The need for stylisation of assessments has also been discussed in the recent NEA document on confidence building[1], see Appendix 1. In some countries, stylised scenarios have been adopted or proposed as the basis for regulatory compliance, e.g. for human actions in respect of the recent compliance demonstration for the WIPP facility and for the biosphere in respect of Yucca Mountain.

This document explores further the role of the analysis of the biosphere and human behaviour in integrated performance assessments with a view to stimulating discussion and to identify further work that may be needed in this area.

REVIEW OF RELEVANT PRINCIPLES AND FACTS

Concerns about potential impacts on the biosphere are paramount in determining waste management options. A few fundamental considerations need to be borne in mind when considering biosphere analysis:

1. "*Waste disposal strategies can be divided into two groups described by two simple labels: Dilute and Disperse, and Concentrate and Retain. Both strategies are in common use*". (ICRP-77) The strategy of concentrate-and-retain is the chosen one for long-lived radioactive waste from national nuclear programmes. This strategy is feasible only because waste volumes are limited and arise either centrally or under controlled conditions allowing them to be collected and documented.

2. Concentrate-and-retain is the preferred strategy when it is affordable. A recognised aspect of this strategy is that, in principle, it is potentially vulnerable to malicious or accidental disturbance and, in some circumstances, it may entail more elevated exposures than the strategy to dilute and disperse. This fact is taken into account when the societal choice is made on which strategy to embark.

3. Concentrate-and-retain can be implemented above or below ground. The choice of geologic disposal is determined by the need to provide substantial isolation and confinement of the waste for time frames that exceed what can be reasonably be planned above ground. Implicit in this choice is the

1 "Confidence in the Long Term Safety of Deep Geologic Repositories - Its Development and Communication", NEA OECD 1999.

assessment that: (a) it is not possible to rely on changes in surface environment and human behaviour that could reduce unwanted effects from the residual toxicity of these wastes; (b) the rate of change of engineered and natural barriers at depth is slower and more predictable than human behaviour and/or the evolution of surface environments.

4. Underground disposal is meant to provide long-term protection under the expected and also less likely physical conditions as well as resistance to (and, therefore, protection against) malicious or accidental disturbance. Moreover, in the long-term, this safety should not rely on monitoring, maintenance and institutional controls. Siting criteria (lack of natural resources) and repository depth are used to reduce the likelihood and the impact of accidental or malicious intrusions. Siting criteria and repository depth are also used to reduce the likelihood and impact of radionuclide releases into the biosphere, e.g., by selecting a site where potential discharges may be highly diluted, and/or where potential discharges would occur in areas with little potable water or, otherwise, inhospitable to man, etc.

5. It is accepted that, in the long term, the dose concept changes its operational purpose to become a "safety indicator", and that, from the point of view of radiation protection, exposures in the far future must be regarded as "potential exposures". Thus, the doses to a hypothetical group at a given location making use of the (hypothetical) local and regional environmental resources, can be viewed as an integral measure of environmental contamination even if it were thought that humans may not be present.

Overall, the biosphere cannot be considered as a safety barrier, although some of its components may be influential on the magnitude of potential exposures in hypothetical, albeit plausible, conditions.

The choice for geologic disposal is partly determined by the desire to avoid the large uncertainty associated with processes taking place on the surface of the earth that are of both human and non-human origin. In order to achieve confidence in the long-term performance of a repository, emphasis is placed on the engineered barrier system and the natural geological barriers, and the protection that they provide. These barriers should provide substantial isolation of the wastes in normal situations and, also, limit the likelihood of, and be robust against damage resulting from accidental or malicious interference.

SPECIFIC CONSIDERATIONS RELEVANT TO BIOSPHERE MODELLING

Having indicated that there is large uncertainty in the evolution of surface environments and human behaviour, and that geologic disposal is a robust means to counter the consequences of such uncertainty, it must be considered that, where specific environments are modelled, there is additional uncertainty in any detailed analysis of the relevant biospheres.

1. Within a time scale of a few thousand years several, very different environmental conditions may be possible at a given site. For example, at coastal sites in Northern Europe, conditions may include marine, freshwater, agricultural, forest, swampland, and even industrial or urban environments under various climatic conditions and climatic sequences which might or might not be influenced by human actions.

2. Results often depend crucially on assumptions which may be difficult to justify, for example:
   - the degree of dilution in the near surface (geosphere-biosphere interface), well, and biosphere,
   - the characteristics and probability of wells,
   - human habits and consumption rates,

– agricultural practices, including irrigation, and associated development of soil properties, erosion rates, etc.

3. Release rates of short-lived daughter nuclides depend on the conditions close to the geosphere-biosphere interface, which are highly changeable and usually not considered in the geosphere-transport analysis. In case of household water, for example, radon (Rn-222) and other short-lived nuclides born close to the geosphere-biosphere interface, are much more important dose contributors than Ra-226 and other long-lived radionuclides considered in the geosphere-transport analysis.

4. Biosphere modelling is very data-intensive. Element-specific K_d values for different soils and sediments, and enrichment factors to milk, meat, fish, various plants and vegetables etc. are needed. Usually they are based on generic literature surveys and not on site-specific measurements. Furthermore, it is questionable whether detailed factors based on present-day consumption and agricultural practices have any relevance to estimation of exposures that will occur in the far future.

5. Calculations of impact assuming present biosphere conditions at a site have also been proposed as one method of illustrating the potential impacts from a repository even where the radionuclide releases to the biosphere will only occur far into the future. This calls for relatively more complex modelling and database development than the simplified stylised calculation and would not be directly applied for judging safety in terms of the associated uncertainties. The results from these calculations can be a useful information, however, especially to local populations to illustrate more meaningfully the potential level of risk.

WAY FORWARD

The discussion above indicates that

- confidence in the long-term safety of geological disposal must be based mainly on confidence in the performance of the engineered and natural (geological) barrier system;

- the future influence of the biosphere and human actions is mainly already taken into account in the siting decision, e.g. in decisions to site away from major centres of populations, to avoid sensitive natural environments, and not to site in regions with known underground resources.

On the other hand, biosphere definition and dose calculations must be done in order to assess the significance of the small residual leakage of radionuclides that may occur at long times in the future and also, possibly, to assess the potential for exposure from accidental disturbance of the repository. A danger is that the potentially large, but speculative, variation related to the future surface environment and human actions may obscure aspects of performance related to the engineered and geological barriers for which more objective assessment is possible. For example, the large variation in possible biosphere assumptions and the complex nature of biosphere pathway modelling could lead artificially to relatively high dose results and, hence, pessimistic views regarding the performance of the facility obscuring the role of the near- and far-field features. The idea of using safety indicators other than dose and risk has been put forward, in part, to counteract this effect. A possible approach for dealing separately with the uncertainties related the EBS/geosphere and those related to the biosphere was proposed in PAAG document NEA/PAAG/DOC(98)6. The main points of this paper are recalled in Appendix 2.

At the international level, it is not clear that there exists yet a common understanding on the role of biosphere analysis in safety assessment, nor of the similarity of the relevant uncertainty with that underlying human action scenarios. ***It seems, therefore, opportune to suggest that within the NEA Integration Group for the Safety Case the "The Role of the Analysis of the Biosphere and Human Behaviour within integrated PAs" receives renewed attention with a view to produce a short report establishing a technical position on this topic.*** This report, and the process to achieve it, would provide international input to both programmatic and regulatory decision making.

In order to collect a wide spectrum of viewpoints and stimulate relevant discussions, a task group could be set up involving participants with both regulatory and developer's background. Exchanges with experts in biosphere modelling, e.g., BIOMASS, are desirable. The topics to be covered would include:

– the basic philosophy of approach to the treatment of the biosphere and human behaviour within IPA, considering its role within decision making and developing necessary confidence,

– the meaning of stylisation as applied in this area, including the definitions of terms (e.g. reference biosphere and benchmark biosphere) taking account of experience gained within actual assessments

– the contribution of reference and/or benchmark biospheres (including for example cases based on the details of present-day conditions at a site) to overall confidence building in PA to different audiences, e.g., their complementary position in relation to other safety or performance indicators, and further technical requirements to improve confidence in this area,

– lessons from the implementation of the reference and/or benchmark biosphere concepts in compliance calculations and the regulatory decision-making process.

In addition, if there is sufficient support, it may be desirable to extend considerations to the treatment of human actions which directly affect the performance of a geological repository. This topic has been considered in the past by a PAAG Working Group[2] and also a RWMC regulator group [NEA/RWM/DOC(95)8]. It is important that the results from these studies should be considered by the Biosphere Task Group since there is the common element of uncertainty stemming from future human behaviour/actions and its treatment in PA. In principle, the philosophy of approach should be same and it would greatly benefit the communication of PA to wider audiences if a consistent international consensus in both these areas can be set down.

Overall these types of issues are germane to the work of the RWMC, the PAAG, and of the future IGSC, and can be inscribed in a long series of documents produced by the RWMC and PAAG. In particular, PAAG members have expressed that the role of the biosphere and associated dose calculations is an area where international consensus would be valuable. The recent IPAG-2 study, NEA/RWM/IPAG(99)2, identified the biosphere as an area where it would be appropriate to apply stylised scenarios that might be internationally agreed, and the recent NEA document on "Confidence in the Long Term Safety of Deep Geologic Repositories - Its Development and Communication" [NEA 1999] stresses a proper treatment of the uncertainties.

Finally, this initiative could take advantage of the recently approved ICRP document[3] to complement the ICRP-46 publication, and would be a useful *complement* to

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2 "Future Human Actions at Waste Disposal Sites", NEA, 1995

3 ICRP Committee 4: Task Group on Radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste. In press.

(a) the BIOMASS programme within which work has now matured and specific examples have become available of reference biospheres, including a case based on well water drinking;

(b) current international initiatives in the field of safety, or performance, indicators.

Suggested actions:

1. Relate to the Bureau-Chairmen group the importance of the subject of biosphere analysis within safety assessment in the general context of the treatment of uncertainty and confidence building.
2. Suggest that a timely initiative, e.g., with the aim to produce a short report illustrating the relevant experience and principles, is desirable.
3. Note that the initiative may not need to be labour intensive. Namely:
   - the present PAAG document could be updated to reflect PAAG comments
   - the new text could be used a basis for discussion within a task group and widely circulated for comments
   - following a topical session at the IGSC, the document would be finalised.

APPENDIX 2: EXTRACT FROM "CONFIDENCE IN THE LONG TERM SAFETY OF DEEP GEOLOGIC REPOSITORIES - ITS DEVELOPMENT AND COMMUNICATION" NEA 1999

The characteristics of system concept will change over time, and the extent to which such changes can be predicted varies between the different elements of the system, according to the uncertainties that affect those elements.

Some uncertainties are amenable to quantification and reduction, whereas others may not be. Examples of the latter are uncertainties regarding:

- Inadvertent human intrusion (although the likelihood of this event can be reduced by appropriate site selection).
- The evolution of the surface environment and the relationship between dose and effect for (diverse) individual human beings.

Rather than attempting to model in detail, or assess the likelihood of, these aspects of the system, a performance assessor may choose to acknowledge that uncertainties make this impractical and to treat the corresponding part of the repository system in a stylised or simplified manner. The performance assessor makes a set of assumptions regarding these aspects, based on, for example, expert elicitation and, where this is available, international consensus. These assumptions may be regarded as a part of the assessment capability. Examples are:

- The definition of a set of stylised human-intrusion scenarios.
- Stylised biospheres and the "standard-man" assumption for the dose-effect relationship.

Such stylised treatments should be traceable, transparent and invoke as few arbitrary assumptions as possible[4]. The acceptability of stylised treatments cannot be decided by the performance assessor alone, although the performance assessor may contribute with suggestions on how to treat such situations. If results for comparison with regulatory criteria are being calculated, then the regulator will judge whether a stylisation is acceptable or not [NEA 1997]. Confidence in the safety indicated by the assessment need not be compromised provided that the documentation clearly acknowledges that these assumptions have been made and that, due to the presence of irreducible uncertainties, the results of the assessments are to be viewed as indicators of system behaviour based on these assumptions, rather than as predictions of consequences that will actually occur in the future (ICRP 1997).

4. The consequences of alternative assumptions regarding the biosphere can be explored using stand-alone biosphere models, and can be used to assess whether the benchmark models are sufficiently conservative with respect to the distribution of potential doses.

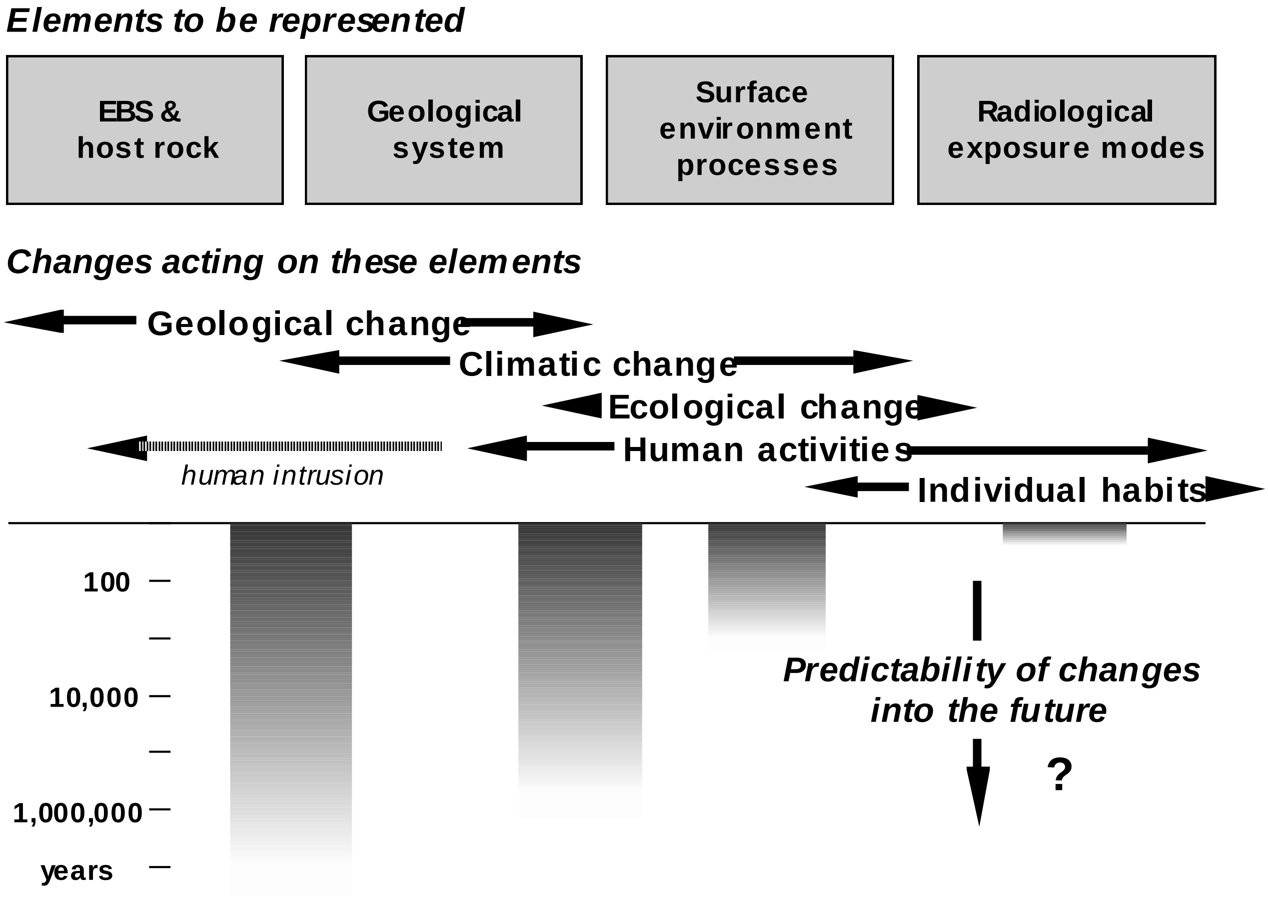

Figure 1 Schematic illustration of the limits of predictability of a geological disposal system

The proposal to treat the analysis of the biosphere in a more stylised manner than other parts of the repository system has precedent in radiological protection, in current assessments, and in the "reference biosphere" approach.

In most nuclear safety applications, a single value of the dose-to-radiological-risk coefficient is adopted and ICRP dosimetric models based on 'reference man' are accepted. This is despite the facts that there is evidence that susceptibility of individual humans to radiation-induced cancers varies widely, and there is variability in body and organ sizes and metabolism between individuals. These variations are not included in radiological performance assessments. We are aware they exist but the measure of concern (at least from a regulatory standpoint[5]) is usually dose or radiological risk calculated according to specified models.

5 The issue of radiation susceptibility is an issue that might, in future, be given greater attention, especially in presentations to the public. The de-coupling of EBS/geosphere system analysis and biosphere analysis that is advocated in this paper, see section 6, could give more flexible opportunities for such consideration, for example, for the exploration of biosphere scenarios which include variations in dose response.

Benchmark biosphere calculations

Understanding of the relevant characteristics the EBS/geosphere can guide design, siting and data acquisition programmes, which can potentially improve safety, or at least reduce the uncertainty in estimates of performance. Although different hypotheses for the nature of the biosphere and of human behaviour in the far future can be conceived, these are speculative. Therefore, it may be convenient to consider these two part of the assessment separately.

With reference to Fig. 2, results for alternative EBS/geosphere scenarios, expressed against a dose scale derived using a benchmark biosphere model, provide a basis for more objective illustrations of safety, and discussion of design and siting options. Results for alternative biosphere scenarios, expressed relative to the results of the benchmark model, provide illustrations of the distribution of potential doses. A key requirement would be to check that the chosen benchmark model is reasonably conservative against this distribution.

The important characteristics of the benchmark biosphere model are that it should be traceable, transparent and invoke as few assumptions as possible. It is also desirable that it is relatively conservative with respect to a range of possible biosphere scenarios, but this is less important, since this can be assessed in detail at a later stage.

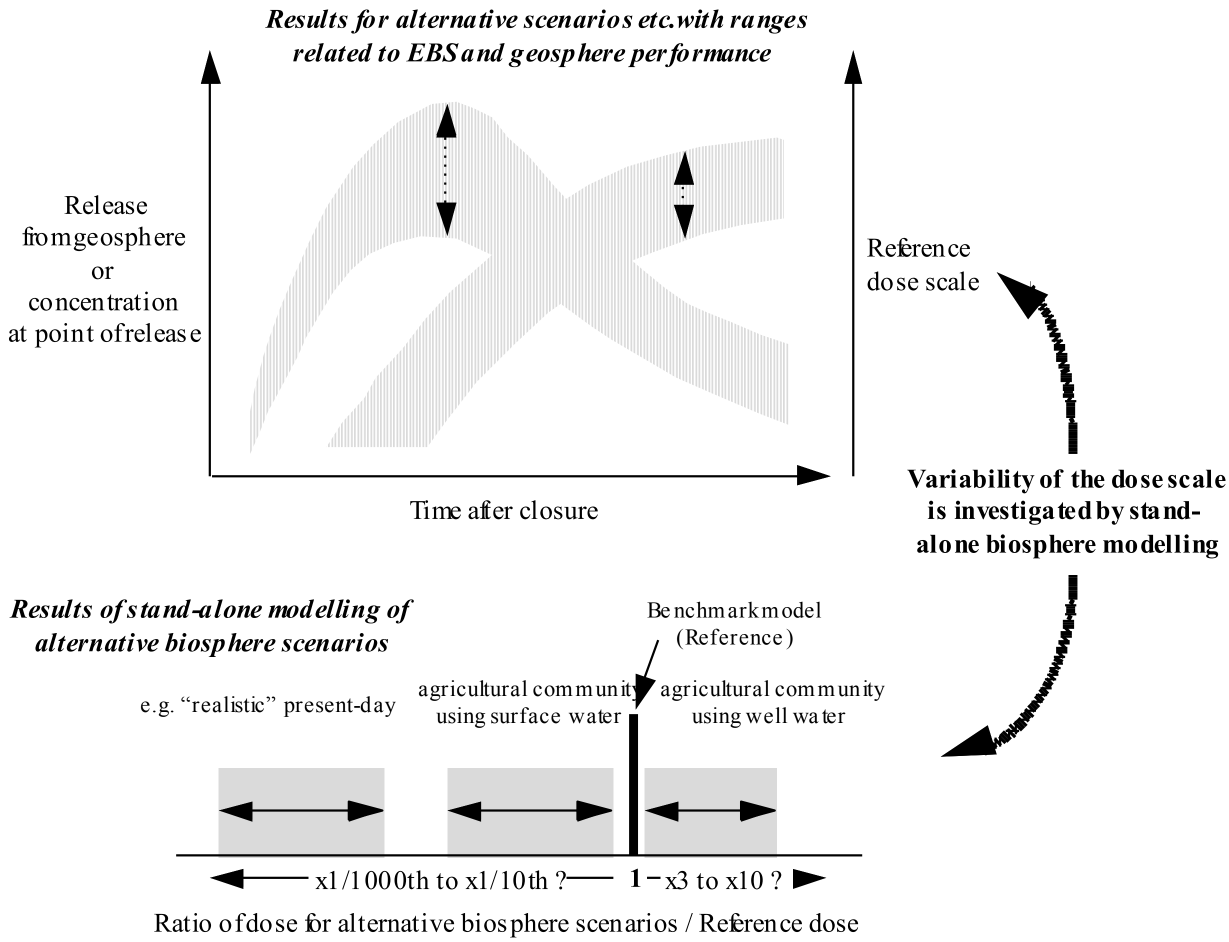

Figure 2 Schematic illustration of the separate evaluation of the EBS/geosphere and the biosphere systems

A well-drinking-water-only model is one possible option for the benchmark model. Advantages of this model are that it is easy to understand, can be applied at most sites and, in order to calculate individual dose, invokes no assumptions concerning humans other than they consume the water at an appropriate rate. It can also be relatively easily adapted to account for different climate states and, thus, linked coherently with geosphere changes related to climate change if these are represented. This is a much more difficult task if a wide variety of dose pathways are represented, and may lead to inconsistent conditions being represented within the geosphere and biosphere models. Additional conservatism can be included by assuming the drinking water is abstracted from the most contaminated source that might constitute a viable drinking water source[6], and that this supplies the total drinking water intake of an individual, e.g. the water is consumed at a rate of $2\ l\ d^{-1}$.

This approach allows the integrated system analysis to concentrate on investigating the influence of variations in the characteristics related to the EBS and geosphere, i.e. those which might impact on siting and design decisions, while also placing the results on a dose scale. The influence of variations related to future biosphere conditions and human behaviour are investigated by standalone biosphere modelling. This can consider alternative water supplies, land use, food sources etc., and also, if required, representations based on present-day conditions and behaviour at the site, and more detailed representations of benchmark model. Thus, it can be determined where the results of the benchmark model fall in relation to the distribution of results from alternative biosphere cases, and a decision can be made on the level of safety offered by the repository and, also, whether the benchmark model is sufficiently conservative with respect to the distribution of calculated doses.

Thus, biosphere modelling can be more responsive to regulatory and public concerns, and a more complete study of alternative biosphere scenarios and their influence on the calculated dose values can be made. Ultimately, the regulator will decide (or agree with the proponent) whether

(a) the benchmark model can be the basis of calculations to demonstrate compliance,
(b) the results on this basis should be factored taking account of results from standalone biosphere modelling, or
(c) an alternative benchmark model should be used.

Advantages/disadvantages

Advantages of the proposed “benchmark biosphere” approach include:

- the benchmark biosphere dose conversion can be simpler and easy to understand;
- few assumptions are needed to define the biosphere model, thus, fewer arbitrary assumptions[7] are folded into the EBS/geosphere performance results;
- biosphere modellers are freer to independently assess a range of biosphere conditions, and compare results to the benchmark model;

6 It is accepted that, in some disposal systems, the most contaminated viable drinking water source is liable to be different under different future environmental conditions, e.g. alternative future climate states or following erosion. These gross aspects of biosphere condition can be taken into account in the system calculations.

7 Biosphere assumptions are necessarily arbitrary, as discussed in Sections 3 and illustrated in Figure 1.

- alternative biosphere scenarios, and resulting range of dose (or dose ratio) results, can be discussed with the regulator and public (in isolation of overall performance results), and a decision made as to whether the benchmark model is sufficiently conservative with respect to the range;
- thus, biosphere modelling can be more responsive to regulatory and public concerns.

Disadvantages of the proposed approach include:

- the relationship between the results from the benchmark model and alternative, more complex, biosphere models will be radionuclide dependent and may have some time-dependence[8]; this may need to be investigated.
- in some disposal systems there may be couplings between biosphere assumptions and EBS/geosphere performance, e.g. the pumping rate of a well may affect geosphere performance; such difficulties can be solved on a case by case basis, e.g. the pumping rate of a well to supply drinking water only should not be high enough to disturb groundwater flows.

Overall, it suggested that the proposed approach will help

(1) integrated performance assessors, by allowing them to concentrate on the analysis of aspects of the disposal system responsible for ensuring the isolation and containment of waste;

(2) biosphere assessors, by allowing them to examine the influence of the biosphere in assessment results more freely, less constrained by the idea that the models they develop will be used directly in regulatory compliance calculations;

(3) the exchange between the proponent, regulator and public, by isolating and allowing separate illustration and discussion of the repository capability to provide the desired level of safety related to EBS/geosphere performance and alternative biosphere assumptions.

8 Time-dependence of the biosphere is not usually a concern for geological disposal systems. It becomes a concern only if the rate of change of radionuclide release from the EBS/geosphere is comparable or faster than the time to reach equilibrium in the local biosphere. This latter time is usually of the order of not more than a few hundred years, even for well-sorbed radionuclides, constrained by soil/sediment erosion processes.