IAEA-BIOMASS-6

# "Reference Biospheres" for solid radioactive waste disposal

## *Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (BIOMASS) Programme*

*Part of the IAEA Co-ordinated Research Project on Biosphere Modelling and Assessment (BIOMASS)*

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## FOREWORD

The IAEA Programme on *BIO*sphere *M*odelling and *ASS*essment (BIOMASS) was launched in Vienna in October 1996. The programme was concerned with developing and improving capabilities to predict the transfer of radionuclides in the environment. The programme had three themes:

**Theme 1: Radioactive Waste Disposal.** The objective was to develop the concept of a standard or reference biosphere for application to the assessment of the long-term safety of repositories for radioactive waste. Under the general heading of "Reference Biospheres", six Task Groups were established:

Task Group 1: Principles for the Definition of Critical and Other Exposure Groups.

Task Group 2: Principles for the Application of Data to Assessment Models.

Task Group 3: Consideration of Alternative Assessment Contexts.

Task Group 4: Biosphere System Identification and Justification.

Task Group 5: Biosphere System Descriptions.

Task Group 6: Model Development.

**Theme 2: Environmental Releases.** BIOMASS provided an international forum for activities aimed at increasing the confidence in methods and models for the assessment of radiation exposure related to environmental releases. Two Working Groups addressed issues concerned with the reconstruction of radiation doses received by people from past releases of radionuclides to the environment and the evaluation of the efficacy of remedial measures.

**Theme 3: Biosphere Processes.** The aim of this Theme was to improve capabilities for modelling the transfer of radionuclides in particular parts of the biosphere identified as being of potential radiological significance and where there were gaps in modelling approaches. This topic was explored using a range of methods including reviews of the literature, model inter-comparison exercises and, where possible, model testing against independent sources of data. Three Working Groups were established to examine the modelling of: (1) long term tritium dispersion in the environment; (2) radionuclide uptake by fruits; and (3) radionuclide migration and accumulation in forest ecosystems.

This report describes the results of BIOMASS Theme 1; Part A (Overview), Part B (Methodology) and Part C (Examples). It has been produced based on Working Material prepared and reviewed by the participants in Theme 1 (see list of Contributors to Drafting and Review). The IAEA wishes to acknowledge the contribution of the Theme 1 Working Group Leader, I. Crossland of the United Kingdom, for the preparation of this report. The support provided for this work by the following organisations is also gratefully acknowledged: Agence National pour la Gestion des Déchets Radioactifs (ANDRA), France; BNFL, United Kingdom; Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT) and Empresa Nacional de Residuos Radiactivos SA (ENRESA), Spain; Institut de Protection et de Sûreté Nucléaire (IPSN), France; Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (NAGRA), Switzerland; Japan Nuclear Cycle Development Institute (JNC), Japan; United Kingdom Nirex Limited (Nirex), United Kingdom. The IAEA Scientific Secretary for this publication was C. Torres Vidal of the Division of Radiation and Waste Safety.

## *EDITORIAL NOTE*

**CONTENTS**

PART B: BIOMASS METHODOLOGY FOR CREATING ASSESSMENT AND REFERENCE BIOSPHERES

## SUMMARY

Theme 1 of the BIOMASS project was established with the objective of developing the concept of 'Reference Biospheres' into a practical system for application to the assessment of the long term safety of repositories for radioactive waste. The outcome is the 'BIOMASS Methodology' developed through the construction of a number of 'Example Reference Biospheres'. The examples illustrate the use of the Methodology and are also intended to be useful in their own right by acting as standard (or reference), stylised biospheres.

BIOMASS METHODOLOGY

The BIOMASS Methodology provides a formal procedure for the development of assessment biospheres in general. It was developed through the creation of the BIOMASS Example Reference Biospheres. The BIOMASS Methodology is 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 summarised in Figure 1.

Defining the **assessment context** is the first stage in the determination of a suitable assessment biosphere. This involves considering: a number of issues that define the overall requirements, principally the purpose of the assessment; the calculational endpoint(s); the site and repository context; the radionuclide source term; the geosphere-biosphere interface; the calculational timeframe; basic assumptions about society; and the assessment philosophy (e.g. the level of conservatism to be applied).

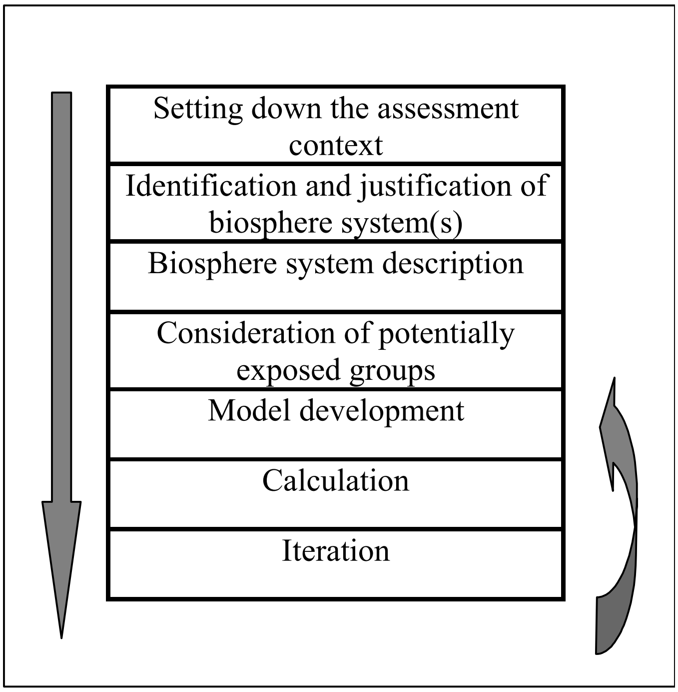


*FIG. 1. Summary of the BIOMASS Methodology.*

Biosphere system **identification and justification** is the second stage of the Methodology. Its purpose is to build on the assessment context to identify and justify the assessment biosphere(s) that is/are to be modelled. Identification and justification takes place in three main steps:

(1) identification of the typology of the main components of the biosphere system (e.g. climate type, geographical extent and topography, human activities etc.) using a series of tables;

(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 changes in sea level;

(3) if biosphere change is to be represented, the third step considers how this should be done. One might, for example, simulate the consequences of radionuclides emerging into a set of separate, unchanging biospheres, chosen to encompass the range of possible futures of interest. Additionally or alternatively, one might wish to consider an inter-related time sequence of biospheres with the interest focussed on the changes from one system to another.

The next stage of the Methodology is to construct a **biosphere system description**. This should provide enough detail about the biosphere system (or systems) to be considered in the assessment 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 semi-natural environment compared to intensive agriculture). Then, for each identified system component, lists of potentially important features events and processes (FEPs) are screened to determine a short list of those thought to be relevant to the assessment. 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 provides a basis for the subsequent identification of **potentially exposed groups** for which radiological exposures are to be considered within the assessment model.

The **model development** stage of the Methodology uses information generated by the second and third stages (system identification & justification and biosphere system description) to construct a conceptual model. The construction of the conceptual model begins by listing the 'media of interest' such as water, soil, crops, animals etc. in which radionuclides may migrate or accumulate. The media are not confined to those that make a direct contribute to radiation exposure so that, for instance, subsoil units may need to be included. Next, the radionuclide pathways through these media (and corresponding FEPs) are identified. Cross checks are made to ensure that the conceptual model incorporates — or at least acknowledges — all the FEPs that were identified as being relevant within the system description. As a final check, the contents of the conceptual model (including those FEPs relevant to radionuclide transport and exposure) are audited against an independent FEP list.

A useful tool developed during the course of this work is a 'radionuclide transfer matrix': a matrix that describes the conceptual model by tabulating the interactions between the media of interest. The matrix would typically be developed through several iterations and in its final form, it shows all the relevant radionuclide transfer and exposure pathways.

The conceptual model should describe the system with sufficient detail and clarity to allow the mathematical equations to be constructed for the mathematical model. There may be a number of alternative mathematical models for any one conceptual model. The availability of data to parameterise the model is an important consideration at this point since this may decide the choice of mathematical model. This and the fact that the data need to be fit for purpose are reasons why data selection is seen as an important activity within the Methodology. The combination of data and mathematical model allows the **calculation**, first of the radionuclide concentrations in the various media of interest and second, of the radiation doses (or other endpoints) resulting from the calculated concentrations in those media.

The Methodology recognises the importance of **iteration**, which allows for changes to reflect improvements in understanding and insight brought about by the Methodology's application.

## EXAMPLE REFERENCE BIOSPHERES (ERBs)

A number of Example Reference Biospheres (ERBs) have been developed. These demonstrate the application of the BIOMASS Methodology while also serving the following three purposes.

(1) the ERBs (up to the stage of defining the conceptual model, at least) are relevant to a wide range of assessment contexts. It should therefore be possible to use the examples as 'benchmarks' against which other assessment biosphere calculations may be compared;

(2) by adopting a series of progressively more complex examples, the examples show the effect of increasing complexity in the assessment biosphere;

(3) by taking the examples all the way through to a numerical endpoint (i.e. using real data), the Methodology is fully exercised. Also, the issue of data selection is addressed though it should be said that the project underestimated the level of effort that would be required to satisfactorily complete the work of data selection.

Three ERBs have been developed that relate to a temperate climate and unchanging biosphere conditions. All three are intended as generic examples: their development is not based on the assumption of a specific location.

— ERB 1 – Drinking water well intruding into a contaminated aquifer;

— ERB 2A – Agricultural irrigation well intruding into a contaminated aquifer;

— ERB 2B – Natural discharge from a contaminated aquifer into a number of different habitats, including arable, pasture, semi-natural wetland and lake.

The project has also produced three further ERBs that have been used to develop the BIOMASS Methodology to allow it to be used to address biosphere conditions changing with time. These three examples are based on two actual locations, Harwell (southern UK) and Äspö (Sweden), for which useful environmental data exist, and a generic site based on the initial biosphere system corresponding to ERB 2A (above). All three examples incorporate changing biosphere conditions and these have been taken through to the 'biosphere identification and justification' stage of the BIOMASS Methodology.

In summary the documentation produced by the BIOMASS Theme 1 project presents a methodology — the BIOMASS Methodology — for the logical and defensible construction of ‘assessment biospheres’, which are mathematical representations of biospheres used in the total system performance assessment of radioactive waste disposal. The Methodology has been used to create a series of 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.

The results of BIOMASS Theme 1 are described in three parts:

— Part A: Overview;

— Part B: BIOMASS Methodology for Creating Assessment and Reference Biospheres; and

— Part C: Example Reference Biospheres.

# PART A

## OVERVIEW

# A1. INTRODUCTION

## A1.1. BACKGROUND

There is a measure of international consensus concerning general safety principles, including radiological protection objectives applicable to radioactive waste disposal. Waste disposal practices should provide for the protection of both current and future generations, and long term safety assessments should provide assurance that future impacts are compatible with those tolerated today. In order to demonstrate compliance with targets and constraints on dose and/or health risk to humans, potential radiological exposures to future populations need to be calculated.

The International Atomic Energy Agency (IAEA) BIOMASS programme on BIOsphere Modelling and ASSessment was launched in October 1996. Theme 1 of BIOMASS was set up with the objective to develop and apply a consistent approach for identifying the assumptions and hypotheses relevant to the definition of biospheres for practical radiological assessment of releases from radioactive waste disposal facilities. Within this objective, a major goal of Theme 1 was to develop a set of example reference biospheres which could provide international points of reference. These were intended as broadly applicable indicators of potential radiological impact for radionuclide releases occurring in the long term.

At the start of BIOMASS Theme 1 there was a need, in the context of individual national programmes for solid radioactive waste disposal, to provide detailed guidance on assumptions appropriate to the development of assessment biospheres used to build confidence in long term safety cases for repositories. There was also general interest in exploring the extent to which internationally defined and agreed reference biosphere(s) might be viewed as "international standard measuring instrument(s)". Guidance on the definition and potential limitations of such internationally agreed measuring instruments was of great interest to all concerned. The scope of BIOMASS Theme 1 was not limited to deep geological disposal although, in practice, much of the work undertaken within the programme concentrated on deep disposal.

BIOMASS Theme 1 identified the following two key challenges for biosphere assessment modelling in the context of solid radioactive waste disposal:

(1) the need to develop a consistent and justifiable set of assumptions and hypotheses regarding the definition of future biosphere systems and potential exposure groups;

(2) the need to put in place a logical and comprehensive framework that combines such assumptions and hypotheses with relevant scientific understanding in order to enable calculations of radiological impact.

This Part provides an overview of work undertaken within BIOMASS Theme 1. The report also provides a 'route map' for the BIOMASS Methodology. Fuller explanation is provided in accompanying Part B, Methodology, and Part C, Example Reference Biospheres. An explanation of how the work developed is available in a series of Working Documents also available from the IAEA.

## A1.2. REFERENCE BIOSPHERE CONCEPTS

Part B describes the problems in demonstrating compliance with long term radiological protection objectives, expands on the reference biosphere concept developed provisionally within the earlier BIOMOVS II programme (Davis et al., 1999) and sets out the strategy for implementation of the concept through development of practical examples. Given that any releases of radionuclides from a deep radioactive waste repository would occur many thousands of years into the future, any description of the biosphere used in the context of radioactive waste disposal assessment could appear somewhat arbitrary. A choice of assumptions has to be made as the basis for the assessment. Taken together however, these choices must be consistent with the aim of providing a robust yet reasonable level of assurance regarding the acceptability of possible future releases from a repository into the biosphere. Reference biospheres should provide a practical way of ensuring that an assessment is based on a good scientific appreciation of the key issues and a wide consensus as to what is robust yet reasonable. This approach broadly corresponds to the suggestion of the ICRP that assessment biospheres should adopt a stylised approach based on general (human) habits and (biosphere) conditions (ICRP, 1998).

The function of the biosphere(s) adopted for the purpose of assessing system performance may be viewed as a form of 'measuring instrument' for evaluating representative indicators of the potential radiological impact of the repository. When integrated with understanding arising from assessments of the behaviour of the disposal system as a whole, such indicators provide an important input to decisions regarding the acceptability of long term system performance. If the biosphere is a kind of 'measuring instrument' an important issue is standardisation. Here a useful analogy may be made with the concept of Reference Man, set out in ICRP Publication 23 (ICRP, 1975). This stated that "although individuals vary considerably, it is important to have a well defined reference individual for estimation of radiation dose". Such a reference individual allows health physicists to compare and check their results without overly 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. It can be similarly argued that, although future biosphere systems and associated potentially exposed humans vary widely, 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 is discussed in more detail in Part B, one point of reference may not satisfy all interests, but a small set may be sufficient for most needs. As with Reference Man, wide use of Reference Biospheres should be helpful in cross-comparing and checking results.

The biosphere(s) adopted for performance assessment should not be regarded as somehow simulating the actual biosphere that will necessarily be present when a future release to the biosphere occurs. Rather, it is appropriate to consider them as adequately representative of possible outcomes for assessment purposes, i.e. as "assessment biospheres". An assessment biosphere can be defined as:

> *"the set of assumptions and hypotheses that is necessary to provide a consistent basis for calculations of the radiological impact arising from long term releases of repository-derived radionuclides into the biosphere."*

The reference biospheres developed within BIOMASS Theme 1 are assessment biospheres, developed specifically to support comparisons. In some cases, the BIOMASS Theme 1

Example Reference Biospheres may be sufficient to meet the needs of a particular performance assessment. This may be especially the case when it would be inappropriate to use data based on information from a specific site: when comparing different disposal concepts for instance. Nevertheless, it is recognised that different assessments have different purposes and that different levels of detail and/or different types of complexity may be required in order to build confidence in the overall performance assessment. Consideration of a wide range of safety indicators as part of the overall assessment context may have significant implications for the approach adopted in defining biosphere systems and modelling approaches. For example, if radiological impacts on species other than man need to be considered, it is likely that the relevant ecosystems to be considered in defining the reference biospheres will be different from those used to determine potential exposures of people.

## A2. BIOMASS METHODOLOGY

### A2.1. BACKGROUND

The original framework for the development of reference biospheres is set out in the Introduction to Part B. A systematic procedure (the 'Reference Biospheres Methodology') for establishing a logical audit trail to justify the scope, constituents and definition of assessment biospheres was developed in the BIOMOVS project (BIOMOVS II, 1996a). BIOMOVS II distinguished the following three main constituents of the methodology:

(a) the context of the assessment;

(b) the basic system, representative of long term conditions;

(c) an awareness of the features, events and processes (FEPs) that are potentially relevant to describing radionuclide behaviour in the biosphere and resultant radionuclide behaviour.

Attention in BIOMOVS II was focussed on developing and demonstrating the logic of the methodology, including the international FEP-list, rather than on development of practical examples of reference biospheres. The methodology provided the necessary logical framework for the development of models relevant to radiological impact assessment for the long term.

The BIOMASS Methodology has been developed from the Reference Biospheres Methodology of BIOMOVS II. Application of the BIOMASS Methodology (Figure A1) to the development of biosphere models for radioactive waste disposal assessment demonstrated that biosphere system descriptions and model development is an iterative process. The need for iteration, which will depend to a large extent on the assessment context, is not reflected in Figure A1.

### A2.2. SUMMARY OF THE METHODOLOGY

The main elements of the BIOMASS Methodology ('the Methodology') for construction of biosphere models are shown in the BIOMASS Route Map (Figure A2). The 'Procedures for screening FEPs and identifying relations between FEPs' that are shown in Figure A1 are incorporated into the tables that accompany Part B. An explanation of the key terms used to describe the biosphere system in the Route Map (and throughout the Methodology) is provided in Table A1 and the Terminology Description.

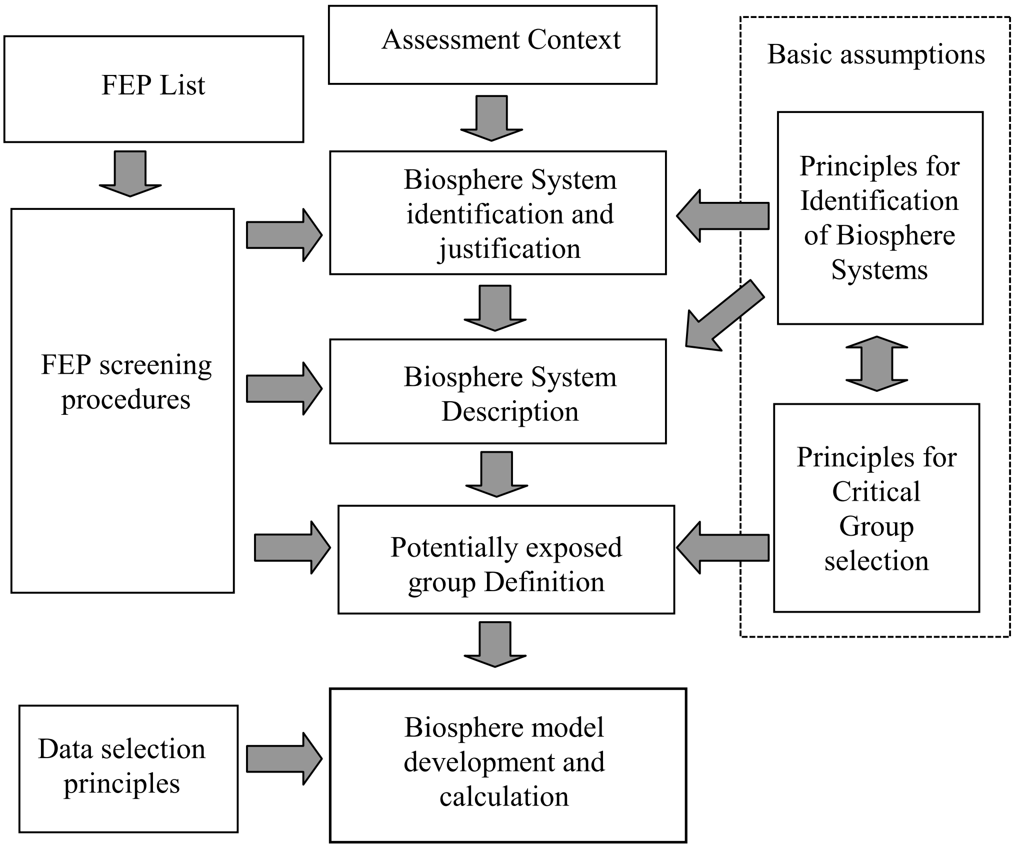


*FIG. A2. Schematic illustration of the BIOMASS Methodology including BIOMASS supplementary guidance.*

TABLE A1. EXPLANATION OF THE RELATIONSHIP BETWEEN KEY TERMS USED IN DESCRIBING THE BIOSPHERE SYSTEM (SEE ALSO THE TERMINOLOGY DESCRIPTION)

| Biosphere System Components | | Characteristics | Conceptual model objects |
|---|---|---|---|
| Principal Component | Principal Component Type | | |
| Water bodies | Lake, river aquifer etc | Geometry, flow rate | Specific water bodies |
| Biotic communities | Community description (woodland, arable etc) | Extent, heterogeneity, flora and fauna | Specific fauna and plants |
| Geology | Soil type, rock type | Minerology, erodability, pH | Specific soils, sediments etc |
| Topography | Coastal, inland, lowland, mountain etc | Altitude, slope, area | – |
| Human activities | Exposure pathways | Quantified habits | Human communities |
| Climate | Desert (zonobiome III), temperate continental (zonobiome VII) etc | Temperature, precipitation | Atmosphere |

**A. SETTING DOWN THE ASSESSMENT CONTEXT**

- Set out what is to be done and why.
- Set out the initial premises.
- Set out context components (parts) e.g. purposes, endpoints etc, and suggest some alternatives.
- Make a clear record of the purposes for the calculation.

The assessment context will help to establish the appropriate level of documentation to provide the necessary traceability and transparency.

**OUTPUT: The underlying premises of the calculation (what is being calculated and why) are stated explicitly.**

↓

**B. IDENTIFICATION AND JUSTIFICATION OF BIOSPHERE SYSTEM(S)**

- Review the assessment context.
- Using the Series I Tables (Part B, Annex BI), select the principal components of interest and then the principal component types for an initial biosphere system, and justify the selection (repeat if more than one system).
- Use the three step process to consider the need for biosphere change (details in Part B, Section B3.1). Repeat step in previous bullet point as required.

**OUTPUT: Biosphere system, or a series of biosphere systems, identified by the principal component types e.g. climate type, topography category etc.**

↓

**C. BIOSPHERE SYSTEM DESCRIPTION**

Note that each of the following steps may require several iterations.

- Step 1. Use the Series II Tables (Part B, Annex BI) to identify which characteristics of the principal component types are relevant or not (i.e. "in" or "out"). In addition, the human activities Table HIIb (Part B, Annex BI) is used to identify potential exposure pathways.
- Step 2. Establish interrelationships between the principal component types of the biosphere system. (Depending on the assessment context this step may not be necessary). Where appropriate use an interaction matrix.
- Step 3. Produce a word picture of the biosphere system. Check for consistency within the biosphere system by carrying out calculations of, for example, water balance. This will require appropriate use of the data protocol.

**OUTPUT: A word picture, which provides a qualitative and, where appropriate, quantitative description of the biosphere system.**

**OUTPUT 2: A description of potential exposure pathways.**

↓

*FIG. A2. The BIOMASS Methodology 'Route Map'.*

**D. CONSIDERATION OF POTENTIALLY EXPOSED GROUPS**

- Step 1. Review exposure modes and routes.
- Step 2. Identify relevant human activities.
- Step 3. Combine human activities and exposure modes to identify those that are most likely to result in the highest doses.

**OUTPUT: List of candidate critical groups and/or other groups of special interest where appropriate.**

The next two steps can follow step 4 of stage E, model development.

- Step 4. Establish data requirements for quantifying hypothetical critical group habits.
- Step 5. Review data availability and select appropriate data making use of the data protocol.

**OUTPUT: Fully characterised exposure groups.**

**E. MODEL DEVELOPMENT**

- Step 1. Identify conceptual model objects i.e. distinct environmental media potentially influencing dose to the candidate critical groups. These media should become evident from screening of Table HIIb (Part B, Annex BI) and the previous formulation of the system description.
- Step 2. Construct the conceptual model by considering the interactions between the conceptual model objects. An interaction matrix has been shown to be useful.
- Step 3. Ensure that no potentially important FEPs are omitted from the conceptual model.
- Step 4. Identify data sources. Define the mathematical model taking account of available data sources and scientific understanding. Derive relevant parameter values according to the data protocol.
- Step 5. Incorporate the exposure group information.

**OUTPUT: Assessment model.**

**F. CALCULATION**

- Calculate concentrations of radionuclides in environmental media.
- Where necessary, carry out calculation of doses to the previously described group(s).
- Iterate as necessary to identify critical group doses.

**OUTPUT: Doses or concentrations as required by the assessment context.**

*FIG. A2. The BIOMASS Methodology 'Route Map' (continued).*

## A2.3. ASSESSMENT CONTEXT

The "assessment context" answers fundamental questions about the performance assessment namely: (a) what are you trying to assess, and (b) why are you trying to assess it? In a quantitative assessment, these questions become: (a) what are you trying to calculate, and (b) why are you trying to calculate it? Historically, these questions had not been answered very clearly and, particularly for the biosphere modeller, the answers were not so simple. There was generally no agreement on what type of dose or risk to calculate - dose to whom, risk of what? (BIOMOVS II 1994, 1996a).

BIOMASS Theme 1 proceeded with the following aims:

(a) to identify components of the assessment context relevant to the biosphere part of a performance assessment;

(b) to identify alternatives for each component, and discuss why and when each is relevant, and identify advantages and disadvantages associated with each alternative;

(c) to consider the implications for biosphere model development, data requirements, documentation etc;

(d) to provide example assessment contexts for use within BIOMASS Theme 1. The examples were selected to reflect relevant perspectives e.g. regulator, operator, status of repository development programme.

In defining alternatives for each component, reference was made to IAEA (1995) which includes the following four principles for radioactive waste management:

— Principle 1: Protection of human health. Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

— Principle 2: Protection of the environment. Radioactive waste shall be managed in such a way as to ensure an acceptable level of protection of the environment.

— Principle 3: Protection of future generations. Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than the relevant levels of impact that are acceptable today.

— Principle 5: Burdens on future generations. Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

It is important that the overall performance assessment context and the context for each part of the performance assessment (such as near field, far field and biosphere) should be coherent and consistent. For example, a consistent approach to treatment of uncertainties is important since the major assessment conclusions are dependent on evaluations made of all parts of the assessed system. This does not mean that exactly the same uncertainty analysis methods must be applied throughout, but that, for example, similar types of uncertainty should be treated similarly, and a consistent approach to pessimistic or realistic choices of parameters should be applied. The scale and speed of change in the biosphere results in the need for different treatments of uncertainty in the biosphere relative to other parts of the system.

BIOMOVS II (1996a) identified components of the assessment context as: assessment purpose; assessment endpoints; repository type; and site context. BIOMASS Theme 1 added additional context components (some of which had been implicitly recognised by BIOMOVS II) concerning: the source term from the geosphere to the biosphere; the radionuclides released; the release mechanisms and other features of the geosphere-biosphere interface; time frames; societal assumptions; treatment of uncertainties; and degree of pessimism to be adopted in choosing parameter values and in other model assumptions (termed 'assessment philosophy').

In real assessment situations, only some components of the assessment context may be provided to the people involved with carrying out the biosphere assessment. The relevant advice may not be available from regulators or from the wider performance assessment context. It is then very important for these components to be specified as part of the biosphere assessment function at the start of the assessment, at least in draft form, as a basis for model development. As work proceeds it may be appropriate to amend the initial assumptions in the light of factors such as data availability

### A2.3.1. Assessment context components

Assessment context components identified within BIOMASS Theme 1 are as described below. Some examples of alternative assessment context components are summarised in Table A2.

TABLE A2. EXAMPLES OF ALTERNATIVE ASSESSMENT CONTEXT COMPONENTS AND/OR REQUIRED INFORMATION

| Assessment context component | Alternatives and/or required information |
|---|---|
| Assessment purpose | • Demonstrate compliance with regulatory requirements/regulatory development<br>• Contribute to public confidence<br>• Contribute to confidence of policy makers and the scientific community<br>• Guide research priorities<br>• Proof of concept<br>• Guide to site selection and approval at later stages in repository development<br>• System optimisation |
| Assessment endpoint | • Individual risk<br>• Individual dose<br>• Collective doses and risks<br>• Doses to non-human biota<br>• Modifications to the radiation environment: Distribution/concentration of repository radionuclides in the environment<br>• Fluxes into or through parts of the biosphere<br>• Estimates of uncertainties or confidence |
| Assessment philosophy | • Cautious<br>• Equitable |
| Repository system | • Depth of repository, host geological medium, waste type |
| Site context | • Spatial extent, surface topography, current climate, surface lithology and soil types, fauna and flora, local surface water bodies and near surface aquifers, the need for biosphere change |
| Source terms and geosphere-biosphere interface | • Well<br>• Water body<br>• Below surface soil<br>• Combination of above<br>• Radionuclide release rates |
| Time frames | • From closure to 100 years<br>• From 100 to 10,000 years<br>• From 10,000 to 1,000,000 years<br>• Beyond 1,000,000 years |
| Societal assumptions | • Intensive or extensive farming and use of modern technology<br>• Simple technology associated with subsistence farming |

#### *A2.3.1.1. Purpose of the assessment*

The general purpose of the biosphere part of a radioactive waste assessment is to determine the radiological significance of potential future discharges of radionuclides. In any specific assessment it may vary from simple calculations to test disposal concepts, through to a detailed site specific assessment to support a disposal license application. To a large degree the purpose of the assessment will dictate the amount of documentation that should accompany an assessment.

#### *A2.3.1.2. Endpoints of the assessment*

The structure and composition of a biosphere model will tend to reflect the results that it is designed to evaluate. These will depend largely on the criteria (regulatory or otherwise) that are adopted to judge the overall performance of the disposal system. Several endpoints may be necessary in developing a safety case for a licensing application.

#### *A2.3.1.3. Assessment philosophy*

Although the nature of the endpoint may have been defined clearly, it is also necessary to make clear the nature of assumptions used in assessment of the endpoint. Exposure group assumptions are an important example but it is clear that the problems with adopting a consistent approach to the level of pessimism can arise in any part of the assessment. A statement setting out the approach to be taken should be included in the assessment context.

#### *A2.3.1.4. Repository system*

The description of the process system to be represented in a biosphere model must be consistent with the known details of the disposal facility being considered, including the type of repository under consideration.

#### *A2.3.1.5. Site context*

The general location of a repository may have an important influence on the likely pathways for release of radionuclides to the biosphere and the extent to which factors such as climate and ecological change can influence the impact of such releases. Site context should identify in general terms the current surface topography and climate in the vicinity of the site. A clear distinction should be made between information that is verifiable and the assumptions made for assessment purposes. The site context may help to define the spatial domain to be included within the biosphere system description.

#### *A2.3.1.6. Source terms and geosphere-biosphere interface*

The structure and modelling requirements of the biosphere model will depend on the radionuclides under consideration and the interfaces assumed between the geosphere and the biosphere. A clear definition of the interface, and recognition of where in the assessment particular processes are being taken account of, is necessary to ensure that all relevant processes are included.

*A2.3.1.7. Timeframes*

To ensure equitable protection of both current and future generations it is necessary to balance greater certainty for shorter time periods with increasing uncertainty over longer time periods. The selection of a specific time frame can have a considerable impact on biosphere modelling.

*A2.3.1.8. Societal assumptions*

During development of biosphere models it is necessary to define assumptions of future human actions. Societal assumptions are dependent on the degree of conservatism or realism desired in the analysis and the endpoints to be considered. Identification of exposure groups to be considered within a biosphere model is based in part on societal assumptions and, if the exposure groups have been identified and defined previously, the societal assumptions should not be inconsistent with that definition.

### A2.3.2. Example assessment contexts

Some examples of assessment contexts initially considered within BIOMASS Theme 1 are summarised below. The different examples arose from the different assessment needs identified among participants, in turn dependent upon the stage of repository development, the details of regulatory requirements, and other factors.

*A2.3.2.1. Example 1*

This example involves a drinking water well, a constant biosphere, a simple geosphere-biosphere interface, and only consideration of individual doses from consumption of well water. A general assumption is that, because of the lack of site data, consideration of human activities is limited to exposure to radionuclides through drinking contaminated water. As a conservative assumption, it is assumed that an individual person abstracts water directly from the contaminated plume in an aquifer and that there will be no monitoring or water treatment. The example is sub-divided into two cases. The first assumes that the contaminated aquifer is not part of the biosphere and the second that it is. (In the latter case, the degree of dilution occurring in the aquifer has to be considered within the biosphere part of the assessment.)

This example is developed in detail in Part C as Example Reference Biosphere, ERB1A and ERB1B.

*A2.3.2.2. Example 2*

This example considers agricultural exposure, a constant biosphere, different types of interface and calculation of individual doses to members of critical groups due to a wide variety of exposure pathways. Two sub-examples are included. In the first it is assumed that the individual is located where it is possible to farm and where the water for all agricultural and domestic needs is supplied through wells in the contaminated aquifer. In the second it is assumed that the individual is located in a valley with abundant water resources sufficient to supply water for all agricultural and domestic uses, and that the contaminated aquifer discharges direct to the surface environment. (In the latter case, a variety of geosphere-biosphere interfaces are considered, involving a variety of agricultural and semi-natural environments.)

This example is developed in detail in Part c as ERB2A and ERB2B.

*A2.3.2.3. Example 3*

This example considers biosphere change. It is assumed that the biosphere has evolved by the time that the release occurs. Three sub-examples are discussed. Two relate to demonstration performance assessments for hypothetical disposal facilities at Äspö in Sweden and Harwell in the United Kingdom. The third case is a non-specific site corresponding to ERB2A. It explores the general implications of a particular Global Climate sequence. So, while the assessment context for ERB2A assumed a constant biosphere, here consideration is given to how such climate change would affect this example. These examples were not developed to the stage of dose calculations. Instead, the focus was on developing the BIOMASS Methodology to make it a useful tool for considering the possible effects of future environmental conditions on radionuclide releases and radiological dose.

*A2.3.2.4. Example 4*

This example (not developed further in BIOMASS Theme 1) was to have considered continuous biosphere evolution as well as additional assessment endpoints, notably environmental concentrations and doses to non-human biota. Two sub-examples were to have been included. The first allowed for gradual change from one biosphere system to another with discharge via wells. The second allowed for continuous modelling of a range of plausible future biospheres with discharge to surface waters.

## A2.4. GUIDANCE ON CRITICAL AND OTHER HYPOTHETICAL EXPOSURE GROUPS

Assumptions regarding the behaviour of human communities are fundamental to the evaluation of radiological exposure as well as the definition of future biosphere systems. BIOMASS Theme 1 considered various aspects of what is involved in the definition of hypothetical future human communities and addressed issues such as self-consistency and conservatism in choice of data as well as questions of homogeneity and averaging. Consideration was also given to whether hypothetical critical groups could or should be defined *a priori* or whether they should be identified on the basis of evaluating a range of potential exposure pathways, *a posteriori* i.e. after the effect of unit exposure to a contaminated medium has been evaluated (Part B, Annex BII, and further discussed below).

Assessment timescales beyond even a few tens, or at most hundreds, of years introduce profound uncertainty into any quantitative description of human behaviour. This means that the biosphere adopted for assessing system performance, in which human behaviour is an integral part, can only be considered as illustrative i.e. as providing indicators of the potential radiological impact of the repository. When integrated with understanding arising from assessments of the behaviour of the disposal system as a whole, these indicators are then used as input to decisions regarding the acceptability of long term system performance.

The concept of ‘critical group’ was originally introduced to address the problem of setting quantitative limits on present-day and near-future releases of radionuclides to the environment. The underlying philosophy was to demonstrate compliance with a dose limit (or more recently, a constraint) based on estimated exposures for a particular subgroup of the total exposed population. Subsequently the term ‘critical group’ became widely used to describe a set of individuals who, because of their location and commonality in their behaviour and habits, were amongst the most highly exposed due to releases from a nuclear facility.

Compared with the detailed interpretation of the critical group concept in the context of routine discharges, the principles for defining human behaviour in relation to long term assessments for solid radioactive waste disposal had received relatively limited attention prior to the start of BIOMASS. Most national regulatory authorities had proposed radiological protection standards for waste disposal that were consistent with the average individual risk levels currently deemed acceptable for large populations. At the same time, regulatory guidance for evaluating compliance also typically required that radiological protection standards should apply to calculated exposures determined using cautious assumptions for a hypothetical maximally exposed population group of limited size. This indicates that an additional margin of assurance had been considered justifiable when developing regulatory guidance for long term future discharges from solid radioactive waste disposal facilities.

To provide assurance that future impacts are compatible with those deemed acceptable today, one could assign habits to future individuals that are similar to those of the present-day population. However, if as a result of climate change and related factors, future releases were to take place in an environment that would be substantially different from that of today, it would be reasonable to expect that some analysis of alternatives, consistent with possible future conditions, should be included.

For some assessment contexts, databases on existing or historic local, regional or national dietary and other habits may be relevant to the assessment. When the assessment context dictates that future environmental change should be taken into account, it may also be appropriate to represent human behaviour on the basis of historical or present-day practices from analogue locations having biosphere conditions similar to the future biosphere(s). As far as consumption of specific dietary items is concerned, BIOMASS concluded that using a figure in the range of the $95^{th}$ and the $97.5^{th}$ percentiles to define a critical consumer group is cautious but reasonable.

Where regulatory benchmarks are in units of collective or population dose or risk, some indication of the potential number of people exposed and the numerical distribution of their exposure is required. For many assessment contexts it may be appropriate to compile assumed distributions of future behaviour into a limited set of behavioural groups. For cases where the definition of a 'critical' group is required, the aim should be to address alternatives for the possible behaviour of a 'reasonably maximally exposed individual' giving due regard to the need for adopting cautious, but reasonable, assumptions.

The information necessary to characterise members of exposed groups can be divided into the following main classes:

(a) general description of the hypothetical exposure group(s);

(b) general description of activities leading to radiological exposure e.g. eating and drinking, washing, type of work, recreation, sleeping;

(c) physiological factors affecting exposure and radiation dose e.g. age, sex and the nature of any physical activity;

(d) location e.g. agricultural or urban land, indoors/outdoors and including the areal extent of the assessment biosphere;

(e) modes of exposure e.g. ingestion, inhalation, external irradiation;

(f) rate and duration of exposure e.g. ingestion rates of different foodstuffs and occupancy times at different locations.

A strategy for identifying and describing a ‘critical group’ is through prior knowledge of likely human behaviour in relation to the ways in which different biosphere resources might be exploited. This strategy can be described as the *a priori* approach because assumptions are made about what exposure routes are likely to give rise to the higher doses before the concentrations in different media have been determined. In contrast, the *a posteriori* approach explores a range of potential combinations of exposure pathways after concentrations in relevant media have been determined, using sampling methods to identify a combination that, whilst not being unrealistic, corresponds to the maximum potential dose or risk within the system under consideration.

Each approach has advantages and disadvantages as described in Annex BII of Part B and neither is recommended to the exclusion of the other. Rather, it is recommended that a combination of the two could be used to establish the final exposed group definition(s).

In line with this recommendation the method used to identify hypothetical critical groups in BIOMASS falls between the *a priori* and the *a posteriori* approaches. A number of hypothetical potentially exposed groups (candidate critical groups) are characterised based on prior identification of specific patterns of behaviour and seeking to relate these to the ways in which different biosphere resources are typically exploited. The most exposed of the candidate critical groups becomes the critical group, the dose to which serves as an indicator of the maximum potential exposure. BIOMASS Examples 2A and 2B included a wide range of exposure pathways. In constructing these examples it was assumed that all the candidate critical groups ate only contaminated foods. This has the effect of producing a relatively small spread in calculated doses across the candidate critical groups, even though these groups include so-called ‘average’ consumers.

## A2.5. GUIDANCE ON APPLICATION OF DATA

### A2.5.1. Background

The quantitative results of assessment calculations ultimately depend on the quality of the parameter database that underlies the calculations. BIOMASS Theme 1 addressed: the definition of “effective” parameters for long term modelling taking into account the different temporal and spatial scales over which data are collected and applied; questions concerning data availability with respect to characterisation of radio-ecological parameters for different environmental conditions; and approaches for addressing data uncertainty. These and other aspects have been incorporated into the BIOMASS data protocol.

The construction of databases for models and the interpretation of data, including the definition of uncertainty bounds on parameter values, have been shown to be particularly important factors contributing to differences in model results and interpretations (BIOMOVS II 1993, 1996b). The derivation of assessment-specific parameters from a wider database of basic biosphere information is a general problem in environmental modelling. It is particularly important in the context of long term biosphere assessments, reflecting the high degree of variability of biosphere characteristics through time, and the high level of discrepancy between existing performance assessment models and reality (Part B, Annex BIII). Past experience has demonstrated that there is an extensive list of issues, or at least constraints, associated with the overall management of data including the following:

(a) there are strong relationships between models and data; each influences the other, and both need to be considered in parallel when developing models and determining parameter values;

(b) data are categorised, they belong to different main families and should be treated differently when gathered and processed according to their type;

(c) there are various sources of data coming from different scientific disciplines and these sources have often been produced for different purposes;

(d) the selection and representation of data to determine a parameter value is not straightforward even if data are available;

(e) there are numerous sources of uncertainty affecting the production of data and the determination of parameter values;

(f) consequently, the available data may or may not be suitable for a given assessment context, and one should react accordingly.

Awareness of these issues has existed since the start of development of assessment models, and the following approaches have been used for controlling them:

(a) direct recourse to expert judgement, sometimes searching for a certain level of consensus, but without following a formal elicitation process;

(b) performance of elicitation exercises combining qualitative and quantitative arguments organised through structured approaches prior to undertaking assessment calculations;

(c) identification of the most important parameters and appraisal of the consequences of uncertainty in their determination through sensitivity and uncertainty analyses following assessment calculations.

One difficulty with the biosphere component of safety assessments of waste disposal is that there is often only partial information in the literature. This reflects the fact that the biosphere component has not usually been addressed in a comprehensive manner, leading to omission of some specific factors such as the variability of data types and heterogeneity in data availability.

Figure A3 illustrates the relationships between data types, data availability, and data requirements in a structured approach to data management. Because of the difficulties associated with the management of data it is not possible to consider this issue as a mere sequential step in the safety assessment procedure. Data management should be considered from the start of any safety assessment exercise since it can influence model development and be resource-consuming. Its treatment should be explicit and properly documented to avoid confusion and possible loss of information. It should interact strongly with other parts of the BIOMASS Methodology as one element of an integrated process that depends on various assumptions (especially from the safety assessment context) and that can influence other parts (e.g. because of data availability). Consequently the treatment of data should involve discussions with people who have different technical backgrounds in order to try to avoid bias and to try to benefit from synergies.

In the BIOMASS Theme 1 data protocol (Part B, Annex BIII) the rationale for data classification method is availability and homogeneity in terms of sources. The protocol applied to branch I (Figure A3) will certainly be extremely simplified but still requires, as for branch II, that data are derived in an explicit and traceable manner. Branch III data could be compiled by implementation of the data protocol by a single assessment specialist since the data are not critical for the assessment. For branch IV data, where data are key to the assessment yet poorly characterised, BIOMASS recommended that selection should be accomplished through expert elicitation and implementation of the full data protocol.

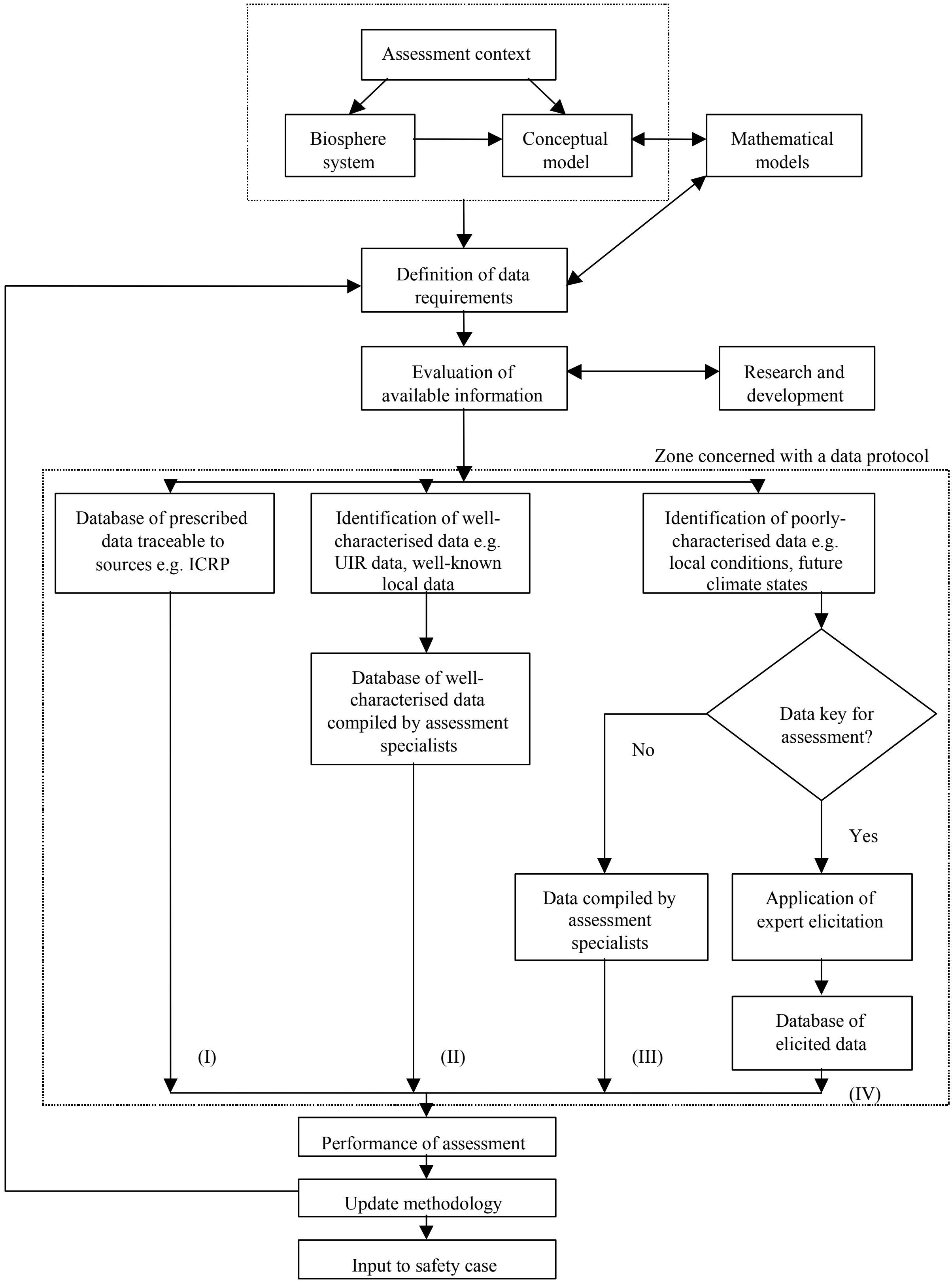


*FIG. A3. Relationships between data types, data availability and data requirements for structured data management.*

The main steps in the data protocol are as follows:

(a) an introduction to take into account the assessment context and other external constraints, and to list the readily available information;

(b) structuring of the information to define fully the quantities under scrutiny and to review the scientific and technical aspects which can govern their determination;

(c) conditioning, where qualitative and quantitative decisions are taken in order to adapt previous knowledge to specific studies;

(d) encoding, where quantitative decisions are expressed, leading to data determination in its strict sense;

(e) adoption of a formal output format – essential for enabling traceability and communication.

Two example applications of the data protocol are provided in Part B, Annex BIII. The first relates to determination of ingestion dose factor from a prescribed source (Figure A3, branch I). The second relates to determination of a soil distribution factor ($K_d$) and a soil-to-plant transfer factor from scientific literature and/or expertise (Figure A3, branch II). It is emphasised that any application of the protocol must start from consideration of the assessment context so as to check assumptions and explain and document any decisions made. An example application of the protocol in the context of derivation of a consumption rate of drinking water at the 95$^{th}$ percentile for young adults is provided in Part C (Section C2).

The data protocol demonstrates the advantages of any structured approach – it should be documented, leading to its understanding even by people who have not been directly involved in its implementation; it should be traceable, allowing the performance of multiple iterations when updates are required; and it should be defensible.

The multiple steps that comprise the protocol should not prevent simplifications based on experience or when regulations clearly impose data choices and when some parameters are known to be less important than others e.g. through sensitivity analysis. The requirement remains to document such decisions and the rationale which supports them.

## A2.6. BIOSPHERE SYSTEM IDENTIFICATION AND JUSTIFICATION

### A2.6.1. Procedure

The justification for choices made in identifying and stylising futures relevant to the evaluation of radiological impacts in the long term is a key step in the development of a coherent assessment approach. The biosphere system was defined in BIOMASS Theme 1 as:

> *"a set of specific characteristics which describe the biotic and abiotic components of the surface environment and their relationships which are relevant to safety assessments of solid radioactive waste disposals".*

The principal components of the biosphere system were defined as: human activities; climate; topography; location and geographical extent; flora and fauna; near-surface lithology; and water bodies.

The approach for identification and justification of the biosphere system (Part B, Section B3) involves three main steps (Figure A4) as follows:

In *Step 1* the assessment context is reviewed to see whether it pre-defines the biosphere system(s) to be considered. If this is not the case then the components of the biosphere system(s) are identified and justified using information from the assessment context.

In *Step 2* a decision is made on the basis of the assessment context as to whether biosphere change is to be considered. If change is to be considered then the mechanisms causing change and the associated potential impacts on the system are identified. Some background to the driving mechanisms for environmental change is provided in Part C, Section C5. When considering the impacts of change it is necessary to take into account the nature of the change, the temporal and spatial scales over which the change occurs, and the speed with which each biosphere system component responds to the change.

*Step 2* needs to reflect consideration of both the intrinsic dynamics of the biosphere system and the extrinsic effects of the 'external environment'. To assist with this, a generic biosphere influence diagram (ID) was developed (Figure A5) for general use as part of the BIOMASS Methodology. This provides for clear identification of initiators, or 'system drivers', whose effects need to be propagated through the external environment. In specific applications, each system driver and interaction would be reviewed to gauge its relevance to the particular site and assessment context. An assessment-specific ID could then be produced and this would be used as the underlying framework for exploring change. Each influence represents an underlying 'model', which may be highly mechanistic, or very qualitative, or a mixture of the two (depending on the specific circumstances of the assessment).

The ID for the biosphere system is effectively a sub-set of the external environment model that is required to define the evolution of the overall disposal process system; it is important to identify the connections between the external environment system and the 'local' biosphere system relevant to the assessment.

Based on the use of the ID framework to guide the identification of system futures, the various decisions involved in Step 2 of this part of the Methodology are expressed as follows. An interaction matrix (IM) may be used to help develop an understanding of the system dynamics.

Screen primary mechanisms for change based on their relevance to the assessment context, with particular reference to those external FEPs identified on Figure A5 as belonging to the external environment of the biosphere system to be modelled.

Identify possible time sequences of change to the system environment, based on consideration of the attributes and characteristics (type, magnitude and timing of change) for the identified initiators or drivers, and propagating their influence through the upper part of the ID.

For each identified time sequence of interest, develop a coherent description of the regional landscape[1] response by propagating projected changes to the system environment through the lower part of the ID, giving due consideration to disequilibria (leads and lags) in the response of the regional biosphere. The projected evolution of the landscape can then be defined in terms of one or more time series of broad-brush descriptions.

[1] Where 'regional landscape' is taken to include both the physical and the environmental characteristics of the region in which the biosphere system is situated.

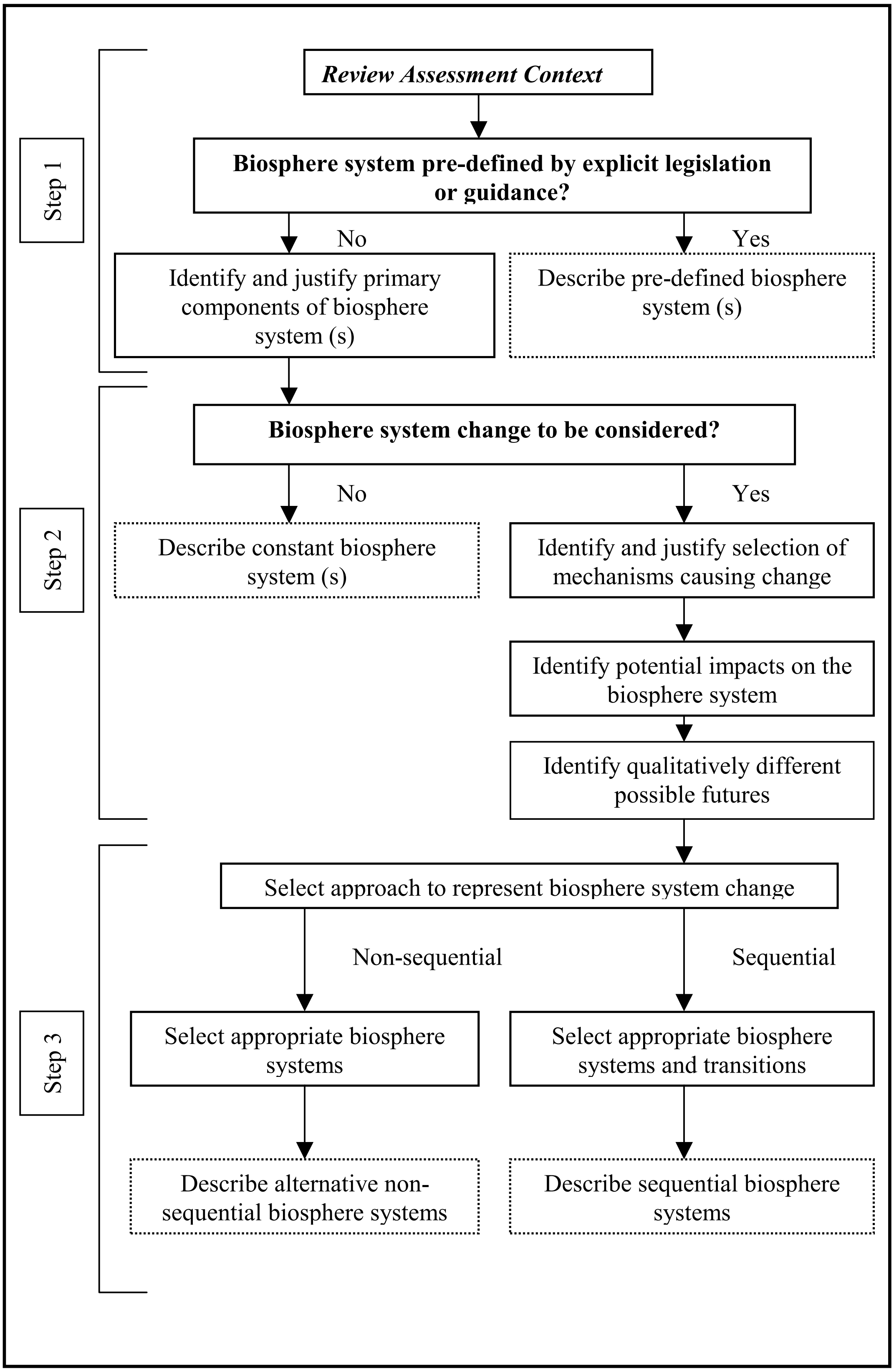


*FIG. A4. Decision tree for use in the identification and justification of biosphere systems.*

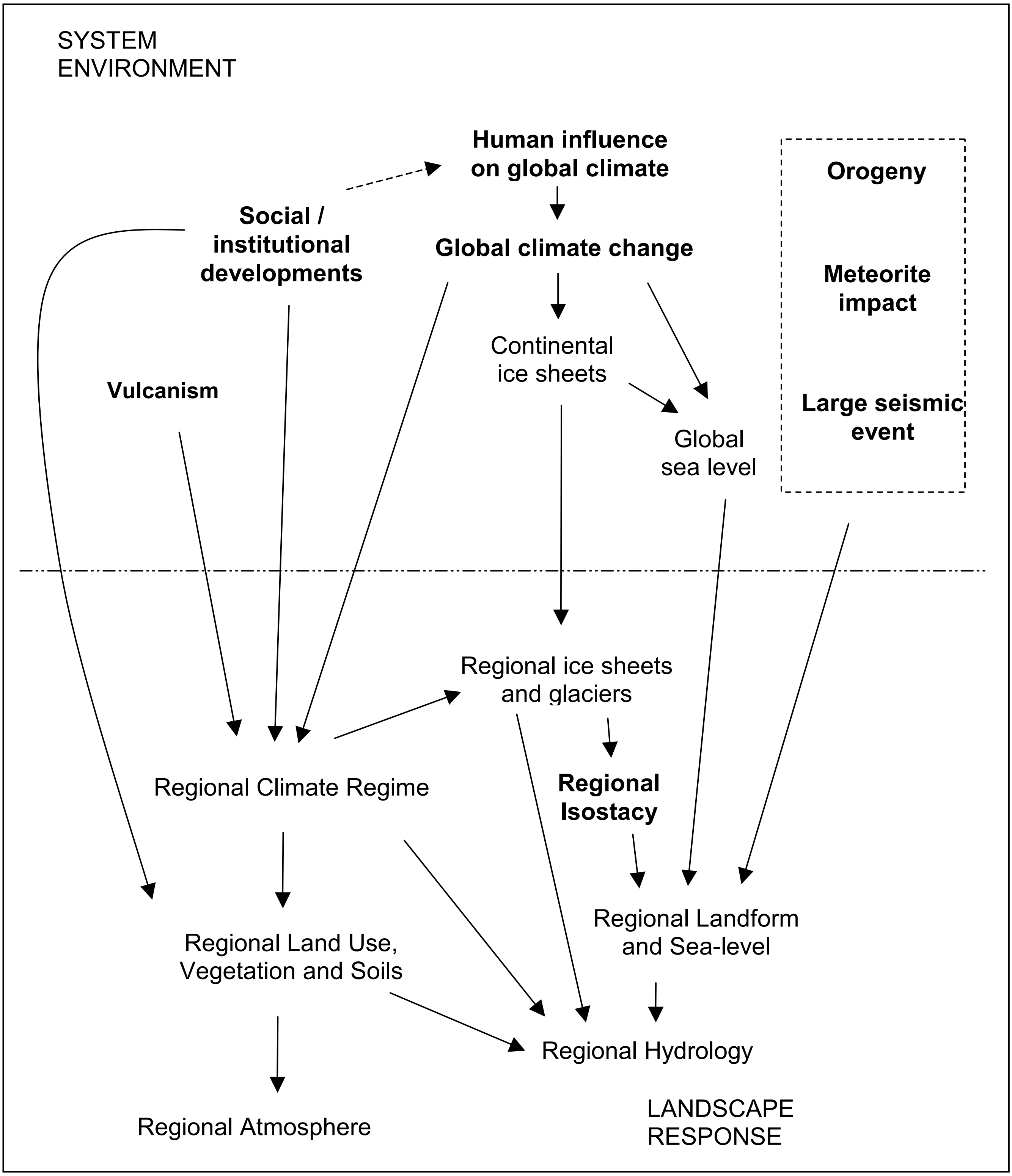


*FIG. A5. Schematic illustration of external FEPs model for describing the influence of change on the biosphere system.*

For each landscape evolution, review relevant assessment context information relating to the source term and geosphere biosphere interface.

Identify and describe one or more time series of assessment biospheres corresponding to each landscape evolution sequence, taking into account the intrinsic dynamics of the biosphere system and changes to its physical boundary conditions as a result of the evolving regional landscape.

Finally, based on arguments relating to the projected behaviour of radionuclides in the evolving biosphere, consider the potential advantages and disadvantages of simulating (within the assessment) the effects of transitions from one biosphere system to another, and define a preferred assessment approach.

*Step 3* of this part of the Methodology involves identifying the particular circumstances and time frames that are most important to the assessment (e.g. from the perspective of potential accumulation of contaminants or radiological impacts) and deciding the best way to represent these. Two approaches to biosphere change were considered within BIOMASS Theme 1, i.e.

The non-sequential change approach, in which alternative (independent) biosphere systems are considered with their particular sequence and duration being disregarded.

The sequential change approach, in which temporal change within any biosphere system and/or from one biosphere system to another is considered explicitly and represented through sequential discrete states or through continuous variation. Each biosphere system would have a 'memory' of the previous system and its components. The change, and its associated impact, might be sudden or gradual and might result from one or more mechanisms such as climate change and/or human actions.

### A2.6.2. Biosphere system principal components

BIOMASS Theme 1 identified a number of principal components of the biosphere system that need to be considered in an assessment. These are summarised in Table A3 along with an indication of the information that should be provided during system identification. Where convenient, 'geology' and 'soils and sediments' may be considered as principal components in their own right (as opposed to being parts of 'near surface lithostratigraphy'). 'Flora' and 'fauna' have a similar relationship to 'biota'.

In some cases it may be helpful to distinguish between primary (essential) and secondary (supporting) biosphere system components. Primary components are defined as those without which the system definition would be considered incomplete. Information applicable to secondary components can potentially be derived from that provided for primary components but may not be relevant for the assessment context under consideration.

### A2.6.3. Biosphere system classification

To assist with biosphere system identification and justification, a series of classification tables was derived, each table corresponding to a different biosphere system principal component (Tables CI, WI, HI, BI, SI and TI of Part B, Annex BI). Table A4 provides an example for human activity classes (Table HI of Part B, Annex BI).

## TABLE A3. PRINCIPAL COMPONENT DEFINITIONS

| Principal Component | Definition | Required information |
|---|---|---|
| Climate and atmosphere | Climate is the expression of meteorological parameters over an area. | At a minimum, climate should be described in terms of broad classification of climate states e.g. temperate, boreal. Atmosphere is defined in terms of composition of the air. |
| Water bodies | Water bodies are the surface and subsurface water masses and may include near-surface aquifers and ice-sheets. | At a minimum, information should be provided as to whether such features are present in the biosphere system. |
| Human activity | Human activity describes the nature of the communities, their habits, level of technology and degree of subsistence. | Nature of the communities, their habits, level of technology and degree of subsistence. |
| Biota | Biota are the terrestrial and aquatic plant and animal life in the biosphere system. | A distinction should be made between domestic and wild flora and fauna and between those which are in the food chain and those which are out of the food chain but used by humans for purposes other than food. |
| Near surface lithostratigraphy | Near surface lithostratigraphy describes the general characteristics of soils and sediments including both their composition and structure. | Near surface lithostratigraphy includes all weathered material above the bedrock and associated life forms (excluding those predefined under flora). It can include bedrocks if they contain aquifers which are to be considered within the biosphere. |
| Topography | Topography is the configuration of the earth's surface including its relief and relative positions of natural and man-made features. | Information should be provided concerning the features of the system under consideration and its relief. |
| Geographical extent | Geographical extent defines the boundaries and/or spatial domain of the biosphere. | At a minimum, the area over which direct contamination of the biosphere may occur should be considered. It should be recognised that extent may change as a function of time. |
| Location | Location is the position of the biosphere system on the earth's surface. | Information concerning latitude and longitude should be provided for site specific contexts. For more generic situations, less specific information might be available e.g. coastal, inland, distance from sea, altitude. |

## TABLE A4. CLASSIFICATION FOR HUMAN ACTIVITY CLASSES ADOPTED IN BIOMASS THEME 1

| Trading | Biosphere management | Community types | Community activities[a] in relation with the system |
|---|---|---|---|
| Minimal | None | Nomadic / Hunter-gatherer | Hunting, gathering, fishing, nomadic herding, direct use of surface waters |
| | Low | Primitive agricultural | Hunting, gathering, fishing, grazing, low yield crop production, selective forestry, direct use of water resources |
| | High | Subsistence agriculture | Crop production, cattle, recycling of residues, use of wood resources, use of water resources |
| Small scale | High | Small farming communities living off local produce | Edible and non-edible crop production, animal husbandry / grazing, recycling of residues, use of wood resources, use of water resources including fish farming. |
| | | Small farming community – external foodstuffs permitted | Edible and non-edible crop production, animal husbandry / grazing, recycling of residues, use of wood resources, use of water resources including fish farming. |
| Large scale trading | Low | Urban with domestic gardening | Use of water resources, gardening, amenity grass management |
| | | Industrial | Use of water resources for industrial production |
| | High | Commercial agriculture | Use of water resources |
| | | • Agriculture / horticulture / sylviculture | Edible and non-edible crop production, animal husbandry, grazing, deciduous / coniferous woodland management |
| | | • Aquaculture | Fish farming, water plant farming |
| | | • Climate controlled farming / "zero-land" farming | Hydroponic crop production, permanently stabled animals, glasshouse horticulture |
| | | • Large scale monoproduction | Edible and non-edible crop production |
| | | Market town | Range of small-scale commercial agricultural practices |
| | | Mineral exploration / exploitation | Land disturbance, use of water resources |

[a] Use of land for residential purposes, and potential exploitation of local water resources, are assumed possible in association with any of the different classes of activities.

### A2.6.4. Application to specific examples

The procedure for biosphere system identification and classification was applied throughout the various BIOMASS Theme 1 Examples. The practicability of the procedure was tested by trial application to the Examples and was revised and adapted accordingly. As an example, Table A5 provides a summary of the biosphere system principal components following the identification and classification stage for Example Reference Biosphere 1, a drinking water well (Part C, Section C2).

TABLE A5. DESCRIPTION OF THE BIOSPHERE SYSTEM PRINCIPAL COMPONENTS DESCRIPTION FOR EXAMPLE 1 (DRINKING WATER WELL) FOLLOWING THE IDENTIFICATION AND CLASSIFICATION STAGE

| Principal component | Description of the Biosphere System Principal Component |
|---|---|
| Human activities | Primary – domestic use of water abstracted via a well. The nature of the community is considered a primary (i.e. essential) component of the biosphere system description because human activities (exploitation of the aquifer as a water resource) are closely linked to the definition of the biosphere system. The assumed abstraction rate must be consistent with domestic usage by the community exploiting the water resource. It is also important to recognise that pumping from an aquifer may alter the natural equilibrium of water fluxes within the biosphere. In order to be consistent with a long term assessment that assumes no biosphere change, the flow field – including the effects of abstraction – must be time-invariant in the long term, although short term fluctuations could be integrated into the definition of the biosphere system. Sustainability considerations will also place a ceiling to the amount of perturbation on the aquifer caused by human actions. The flow field is then considered to have reached a long term equilibrium. |
| Climate | Primary – temperate, present day. Climate characteristics are considered a primary (i.e. essential) component of the biosphere system description insofar as evapo-transpiration and precipitation will influence the recharge of (and natural discharge from) the aquifer, and temperature (for example) may affect the water requirements of the local community. Short term fluctuations in annual climate may influence requirements for the development of temporary storage facilities. |
| Topography | Secondary – detailed consideration of topography is not a significant element of the biosphere system. The assessment context indicates that the primary consideration is the flow field in the aquifer. Factors affecting this flow field are not fundamental to the system description, although they may be relevant to a detailed understanding of the system. Indeed, for a specific site, characterisation of this flow field would be the important concern, whether or not this was determined by consideration of topographic (and litho-stratigraphic) considerations. |
| Location | Secondary – not a significant component of the biosphere system for a generic assessment context. The assessment context requires only that consideration be given to exposures incurred via the direct consumption of drinking water abstracted from the aquifer under present day temperate environmental conditions. However, in any practical use of the assessment model corresponding to the assumed biosphere system, the location of the well needs to be consistent with the availability of water in sufficient quantities at an accessible depth. |
| Geographical extent | Primary – limited to the region of the aquifer and the well from which the contaminated water is assumed to be abstracted, together with any distribution system for water used by the community. Geographical extent is therefore important in so far as the physical domain of interest is constrained by the requirements of the assessment context. The assessment context also requires that the aquifer should be at 'accessible depth'. |
| Biota | Secondary – not a significant component of the biosphere system relevant to the assessment context. It is nevertheless recognised that flora and fauna (particularly deep-rooted trees) may have an important impact on the sub-surface flow field; although not fundamental to the required biosphere system description, they may be relevant to a detailed understanding of the system. |
| Lithostrati-graphy | Primary – the lithology of the aquifer needs to be described because the assessment context requires that the aquifer is considered as part of the biosphere system in this example. |
| Water bodies | Primary – the assessment context specifies that an aquifer capable of supplying water of potable quality is to be considered as part of the biosphere system. There is a need to describe the characteristics of the aquifer (flow field, mineralogy, accessibility) in such a way as to provide an interface with geosphere models and to ensure consistency with domestic use. |

## A2.7. BIOSPHERE SYSTEM DESCRIPTION

Having identified a list of biosphere systems relevant to long-term assessment, the next step is to provide practical and self-consistent stylised descriptions of such systems. This involves characterising the spatial domain, constituents and system dynamics, taking into account underlying assumptions regarding human behaviour as well as the overall assessment context. Descriptions that form a basis for assessment modelling should be considered independently of any potential radionuclide input, thereby addressing broader concerns regarding assumptions that support the safety assessment. The validity of the system description was addressed in BIOMASS Theme 1 by systematic consideration of potentially relevant FEPs as well as by informed and consistent choices regarding quantification of system parameters.

The procedure that leads to the biosphere system description must characterise the biosphere system principal component types, to allow them to be represented in the assessment model. Of course, the assessment model does not exist when the Methodology has only reached the system description stage. In practice, therefore, a degree of iteration (rather than a simple once-through procedure) will often be required. The aim is not so much to derive a complete, detailed description of a hypothetical biosphere system from the "bottom up", but to ensure that the various elements used to support the radiological assessment are broadly coherent. Thus, for example, an initial version of the biosphere system description might be used to support the preliminary development of radionuclide transport and exposure pathways for a specified assessment context. To the extent that modifications can then be identified to help ensure that the perceived assessment requirements are met, and that available data to support the models are used most effectively, the biosphere system description (and other outputs from the model development process) may need to be refined further.

### A2.7.1. Procedure for biosphere system description

An iterative approach, based on increasingly refined descriptions of the system, allows coherence to be maintained whilst providing a level of detail appropriate to the overall assessment context. Nevertheless, the following main steps can be identified.

#### *A2.7.1.1. Step 1: Selection of relevant characteristics of identified biosphere system prinicipal component types*

In this step the relevant characteristics of the identified biosphere system principal component types (as determined by the system identification described above) are selected, based on screening of information given in Type 'II' Tables (Part B, Annex BI). Table A6 provides an example of one of these screening Tables as developed for biotic communities. Such screening needs to take into account the underlying assessment context, including the geosphere-biosphere interface and the endpoints of the assessment, but could also invoke modelling judgements regarding the likely significance of particular characteristics. It is recognised that there may be situations where it is unclear whether or not particular characteristics are relevant to the biosphere system description, and these will need to be retained for review later in the procedure. For example, a characteristic may be relevant to describing the behaviour of one particular radionuclide but not to others.

TABLE A6. EXAMPLE TYPE II SCREENING TABLE (BIOTIC COMMUNITY CHARACTERISTICS)

| Characteristic | Comment |
|---|---|
| NET PRIMARY PRODUCTIVITY | Rate at which energy is bound or organic material created by photosynthesis after accounting for respiration per unit area per unit time. |
| NET SECONDARY PRODUCTIVITY | Net productivity of heterotrophic organisms – animals and saprobes |
| BIOMASS/STANDING CROP | Dry weight per unit area. Plants, animals, other organisms. |
| CROPPING | Rate of removal by humans. Animals and animal products, plants and plant products, other organisms and their products. |
| POPULATION DYNAMICS | Plants, animals and other organisms. |
| VEGETATION CANOPIES | Physical structure. Interception of light, water, aerosols, vapours and gases. |
| PLANT ROOTS | Structure and distribution with depth. Absorption of nutrients and water with depth. |
| ANIMAL DIETS | Composition and quantity. |
| BEHAVIOURAL CHARACTERISTICS | The part of the ecosystem in which an animal forages and the time it spends foraging in different parts of the ecosystem, including management aspects where applicable. Animals and other mobile organisms. |
| CHEMICAL COMPOSITION and CHEMICAL CYCLES | Including sources and sinks. Major and minor nutrients, trace elements. |
| METABOLISM | Animals, plants and other organisms. |

Note: VARIATION WITH SPACE is dealt with under Extent and Heterogeneity) and VARIATION WITH TIME (Diurnal, Seasonal, Annual or other) is dealt in the appropriate descriptive characteristics.

### *A2.7.1.2. Step 2: Establish interrelations between biosphere principal component types*

In documenting the screening decisions, a record must be kept of which items are considered relevant, potentially relevant or not relevant to the overall biosphere system description and the reasoning behind the decision. The output of this step will therefore be a record of:

(a) those biosphere system characteristics that are considered relevant, or potentially relevant, as a basis for developing a model that meets the overall assessment objective; and

(b) those characteristics that can be justified as not relevant to the scope of the assessment.

Step 2: Having characterised the biosphere system principal component types it should be evident which are relevant (or potentially relevant) to the assessment calculation. Step 2 then involves establishing the ways in which the principal component types are interrelated, thereby providing a phenomenological description of the intrinsic dynamics of the biosphere system. This can be achieved by constructing a (phenomenological) interaction matrix (IM) to identify important phenomena based on analysis of the interactions (i.e. relationships and dependencies) between the biosphere system principal component types. The IM approach also provides a clear way of ensuring that each of the interactions can be 'mapped' into the assessment model. Moreover, the systematic process of examining how the biosphere system principal component types relate to one another may help to identify previously unrecognised relevant characteristics of the biosphere system. An example of such a phenomenological interaction matrix, based on a biosphere containing four habitat types is shown in Figure A6 (based on Example Reference Biosphere 2B).

| | 1 | 2 | 3 | 6 |
|---|---|---|---|---|
| 1 | Area 1 - Wooded | Wind - aerosols and volatiles<br>Groundwater flow - sub-horizontal flow at phreatic surface<br>Surface water - surface run-off when precipitation rate exceeds vertical hydraulic conductivity<br>Soil – solifluction<br>Use of ash as fertiliser<br>Deposition of ash from burning<br>Wood products<br>Organic detritus<br>Manuring using animal waste, temporarily grazing farm animals | Wind - aerosols and volatiles<br>Use of ash as fertiliser<br>Deposition of ash from burning<br>Wood products<br>Organic detritus<br>Animal foods | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Wood products<br>Organic detritus |
| 2 | Wind - aerosols and volatiles<br>Deposition of ash from burning | Area 2 - Arable Crops | Wind - aerosols and volatiles; Groundwater flow - at phreatic surface; Surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Interflow mediated by natural features and drains; Soil - solifluction<br>Deposition of ash from burning<br>Organic detritus<br>Animal foods | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus |
| 3 | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Domestic animals and animal waste | Wind - aerosols and volatiles;<br>Manuring using animal waste<br>Deposition of ash from burning | Area 3 - Grassland | Wind - aerosols and volatiles<br>Groundwater, interflow, surface water - stream recharge; soil – solifluction<br>Deposition of ash from burning<br>Organic detritus |
| 6 | Wind - aerosols, volatiles and spray<br>Water - ingestion by animals | Wind - aerosols, volatiles and spray<br>Sediments - dredged and deposited to enhance soil; Water - ingestion by animals | Wind - aerosols, volatiles and spray<br>Groundwater recharge from stream; Sediments - dredged and deposited to enhance soil; Water - ingestion by animals, overbank flooding | Area 6 - River and Lake |

Note: Humans and birds can move between all of the habitats

*FIG. A6. Phenomenological interaction matrix for a temperate biosphere system containing four habitat types.*

### *A2.7.1.3. Step 3: Basic description of the biosphere system*

In Step 3 the information derived through Steps 1 and 2 is used to provide a qualitative description of the biosphere system. This description should include consideration of the characteristics relevant to each principal component type and the ways in which they are interrelated, both in terms of system dynamics and their assumed spatial arrangement. The result can be considered a 'word picture' of the biosphere system; in practice, a combination of verbal and pictorial description of the biosphere may be helpful, depending on the circumstances of the assessment. Descriptive parameters are also desirable at this stage in order to provide a more substantive account of (for example) the spatial scale of the particular features that may be identified within the local environment to be represented in the model and the magnitude of the system dynamics. When no site specific information is available to guide such decisions, other generic information needs to be used. Annex BV of Part B provides a guide to typical natural correlations and relationships between biosphere system principal component types and their characteristics.

## A2.8. BIOSPHERE MODEL DEVELOPMENT

The assessment context (incorporating the overall premises of the assessment approach), the biosphere system description, and the exposure group definition all need to be addressed during model development. BIOMASS Theme 1 focussed on development of conceptual model definitions and the systematic definition of model components, relationships and boundary conditions taking into account the range of FEPs identified by BIOMOVS II (BIOMOVS II 1996a).

The starting point for simulating radionuclide transport and accumulation is a description of the biosphere system (including the human community) in which it is assumed that exposures could take place, coupled with a description of the assumed geosphere-biosphere interface for radionuclide release into the system. The development and justification of an assessment model will not always be a simple process; an iterative approach to refining the model, coupled to enhancement of the corresponding biosphere system description, may be necessary in order to ensure that a practicable and justifiable approach is achieved. Nevertheless, the following main steps can be identified (Part B, Section B5):

- identify the biosphere system principal component types that are to be designated as separate conceptual model objects (i.e. distinct environmental objects or media) in the representation of radionuclide transport;
- taking account of the assumed spatial configuration and intrinsic dynamics of the biosphere system principal components, devise a conceptual model of radionuclide transport between these conceptual model objects;
- ensure that all relevant FEPs are addressed adequately within this representation of radionuclide behaviour in the system, taking account of the phenomena identified in the biosphere system description;
- define the mathematical model, taking into account available data and scientific understanding related to the phenomena of interest.

These steps allow a conceptualised description of the dynamics of radionuclide transport through the biosphere to be developed. This can be achieved in a variety of ways. Within BIOMASS Theme 1, interaction matrices (IM) have been used to provide a condensed representation of transfer pathways. This application of the IM is acknowledged to be different from its earlier use, as part of the procedure for biosphere system description, where it provided a comprehensive basis for identifying phenomena responsible for the influences of one component of a system on another. However, one advantage of adopting a similar method of presentation to that used in developing the system description is that it is easier to provide an audit trail demonstrating how relevant biosphere system phenomena are ultimately represented as FEPs in the conceptual model for radionuclide transport.

A simple example of the first stage in developing a matrix representation of the conceptual model is illustrated in Figure A7. The leading diagonal elements (LDEs) of the matrix correspond to the various media that have been identified as being relevant conceptual model objects in the representation of contaminant migration within the hypothetical biosphere system and in the evaluation of radiological impact. In practice, the number of leading diagonal elements used to represent the conceptual model will depend on the required complexity of the biosphere system and the geosphere-biosphere interface. For the example presented in Figure A7, it is assumed that the biosphere system consists only of agricultural land irrigated by water from a contaminated aquifer.

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

*FIG. A7. Simplified interaction matrix representation of a conceptual model for radionuclide transport in a biosphere system based on an agricultural (irrigation) well.*

[The leading diagonal (shaded) elements show the relevant 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 part or a feature of the mathematical model. 'x' signifies no radionuclide transfer in this conceptual model.]

In more complex examples where there is more than one geosphere-biosphere interface, it may be helpful to introduce the geosphere-biosphere interface into the IM explicitly by adding an additional LDE to represent the source of the contamination (the source term). In Figure A7 this would be the aquifer itself. Interface issues can then be addressed as interactions between the Source Term and other LDEs. An additional final LDE could also be included to represent a radionuclide sink: the loss (whether by radioactive decay or migration) of radionuclides from the domain of the biosphere system of interest.

The conceptual representation of the biosphere system is completed by identifying all FEPs that are associated with contaminant transport between those environmental media that have been represented as separate conceptual model objects. Off-diagonal elements (ODEs) of the matrix therefore correspond to FEPs associated with radionuclide migration and accumulation in environmental media. Radionuclide transport pathways will depend on the assumed configuration of the biosphere system components, as outlined in the system description.

During completion of the IM representing the conceptual model for contaminant transport, it is important to recognise that more than one FEP can appear in any given matrix element and that any particular FEP can, as appropriate, appear in more than one element. Leading diagonal elements would normally be assumed to represent 'Features' however it is also quite possible for them to incorporate 'Events and Processes'. For example, a LDE representing a surface water body might be defined such that it implicitly incorporated the advection, dispersion and settling of contaminated materials within the water column. If a more detailed conceptual representation of events and processes intrinsic to a specific LDE was necessary as a basis for selection of a suitable mathematical model, this could be explored at a greater level of detail by expanding the IM to incorporate additional LDEs. The further disaggregation of the biosphere system in this way, to ensure that a suitable model structure is adopted, is an example of the iterative approach for refining the model and the biosphere system description.

To provide a coherent justification for screening FEPs in the conceptual model, it is important to be able to trace the relationship between the conceptual model for radionuclide transport and the underlying biosphere system description. In developing a systematic audit trail, it is helpful to provide a record showing how all phenomena that were identified as 'relevant' within the biosphere system description were addressed in the treatment of FEPs in the conceptual model for radionuclide transport. This record should indicate:

(a) those phenomena that were represented in the conceptual model, with their corresponding location as FEPs within the IM;

(b) those phenomena that were screened out from consideration during development of the IM, with reasons for their omission;

(c) those FEPs that correspond to additional phenomena that were introduced as a result of development of the IM.

Mathematical representation of the conceptual model depends on a good understanding of the importance of FEPs to long term radiological assessment and the best ways in which they can be described mathematically. Modelling constraints, such as the preferred solution method to be adopted within the assessment tool, may restrict the ability to represent particular events or processes and thereby lead to revision of the list of FEPs included. Separate models may need to be developed if FEPs cannot easily be combined into a single model.

During development of the mathematical model, or models, a list of parameters relevant to the calculation will be identified. Each of these, and their specific meaning within the context of the model, should be documented in order to provide a clear basis for establishing the necessary databases. In practice, the mathematical representation of many processes tends not to be explicit, but is instead based on an empirical model of effects observed at the system level. An empirical model of this type can represent the combined action of several FEPs identified separately within the IM. Where this is the case, care needs to be taken in order to avoid double-counting the effects of certain processes or, conversely, the inadvertent exclusion of potentially relevant FEPs.

## A3. EXAMPLE REFERENCE BIOSPHERES

### A3.1. BACKGROUND

Over the very long periods of time associated with safety assessments for the disposal of solid radioactive waste, it is likely that there will be major changes to the surface environment. The biosphere element of a long term assessment serves as the means for interpreting the projected technical performance of a disposal facility in terms of radiation protection objectives; it has to cater for substantial uncertainty with respect to the circumstances in which future radiological impacts may occur. Hence, quantitative evaluation against radiation protection objectives requires the identification and justification of ‘assessment biospheres’ that are sufficiently representative of possible future environmental conditions to be able to provide an adequate indication of the potential exposures that might be incurred.

A systematic process (the Reference Biospheres Methodology) for justifying the scope, constituents and organisation of biosphere models applied to solid radioactive waste disposal assessments was originally described by BIOMOVS II (IAEA, 1996). BIOMASS Theme 1 undertook further development this methodology by using it to create practical Example Reference Biospheres (Part C). These Examples serve a number of purposes. They demonstrate how biosphere models for long term assessment (assessment biospheres) can be developed. They have been used to investigate the implications of adopting different assumptions in the biosphere model development. And they have been used to develop and demonstrate the practicability of the BIOMASS Methodology.

The use of generic ‘reference case’ assessment biospheres can provide some assurance that, over the very long term, a reasonable level of caution has been adopted in the determination of radiological safety performance. By developing worked examples, one aim of BIOMASS Theme 1 was to explore the extent to which a limited set of such generic representations might usefully be seen as ‘standard measuring instruments’ – Reference Biospheres – for long term assessment. Such standard tools could be helpful in demonstrating compliance with radiological protection objectives as part of an authorisation or licensing procedure for a particular facility. More generally, it is expected that the assessment biosphere(s) used in support of long term performance assessment will need to embrace an appropriate mix of both site specific and more general considerations.

According to the particular circumstances in which the assessment is made, it may be appropriate to follow simple or more complex approaches in addressing the biosphere. The series of Example Reference Biospheres explored in BIOMASS Theme 1 was designed to give consideration to a range of issues that are of potential interest in the context of solid radioactive waste disposal for a variety of hypothetical assessment contexts (see Section A2.3). Very simple assessment biospheres are potentially open to criticism for being too coarse a representation of the features, events and processes that can be relevant to determining the radiological significance of projected releases in the long term. However, the incorporation of additional complexity, with the objective of addressing such concerns, can introduce other difficulties. For example, it is necessary to consider whether the information requirements and related uncertainties associated with more complex assessment biospheres are in proportion to their role in contributing to safety assurance.

Clearly, any assessment biosphere, however complex, can do no more than provide an indicator of the level of protection provided by a disposal system in the long term. The purpose of the BIOMASS Theme 1 Examples is to inform discussion of the potential implications of addressing different levels of complexity in biosphere assessments for solid radioactive waste disposal and their value as a guide to decision making. Each Example is discussed below and the overall set of results and their use is discussed in Sections A4 and A5 respectively.

## A3.2. THE DRINKING WATER WELL (EXAMPLE REFERENCE BIOSPHERE 1)

This Example Reference Biosphere (ERB) (Part C, Section C2) was designed deliberately to be very simple, being focussed on a simple biosphere system and a single exposure pathway. It is characterised by a drinking water well bored through the overburden into an aquifer that has become contaminated by radionuclide releases from the repository. The Example was explored in two variants. In the first (ERB1A), it is assumed that a geosphere model for the site of interest is able to support calculation of radionuclide concentrations in well water. In the second (ERB1B) it is assumed that the biosphere model domain includes the near surface aquifer from which the well water is drawn. Part C, Section C2 sets out the basis for derivation of the resulting reference biosphere, the numerical results for both variants, and the caveats that must be observed in connection with the calculations and application of the results.

It is recognised that different levels of detail and/or different types of complexity will often be employed as part of a comprehensive performance assessment. The assumption of an uncomplicated biosphere – such as a well used for drinking water – might therefore be relevant as an element of the ‘multiple lines of reasoning’ used to build confidence in the overall assessment. As such, the resulting Example Reference Biosphere provides a simple illustration of the potential radiological significance of potential future discharges, and could assist in the identification of key differentiating factors in total system performance, such as the design and/or representation of engineered barriers, or the geological host formation. This might, in turn, assist with providing proof of concept, in guiding research priorities, or as part of a site screening programme.

The simplicity of the Example serves clearly to identify where key questions lie in relation to the geosphere/biosphere interface. Example Reference Biosphere 1A is intended as a realistic reflection of the way in which some assessments are carried out, assuming that radionuclide concentrations in well water can be supplied externally to the biosphere calculation. This implies that all relevant flow and transport effects within the regional groundwater flow system, including changes to flow boundary conditions in the aquifer arising as a result of pumping and other changes that may occur within the well itself, would need to be addressed in geosphere models. By contrast, the geosphere/biosphere interface for ERB1B corresponds to a pre-defined ‘release rate’ of radionuclides (Bq/y) from the geosphere to an aquifer that is considered to lie in the biosphere. This Example therefore requires the conversion from Bq per year into the aquifer to Bq per cubic metre of water emerging at the well head to be calculated as part of the biosphere model. The intention was that definition of the interface for ERB1B should realistically reflect the way in which performance assessments are often carried out, requiring quantitative biosphere assessment calculations to be undertaken on the basis of relevant site characteristics and the rate of release of radionuclides from the geosphere. Effective communication between modelling teams responsible for either side of the notional geosphere/biosphere interface is clearly required.

An important factor affecting the description and conceptualisation of the biosphere system, as well as parameter choice, is the ultimate endpoint of the calculation. For this Example Reference Biosphere, the assumed assessment context identified the endpoint as the evaluation of ‘annual individual effective dose’ from consuming contaminated well water. It was deliberately not specified whether this was intended to represent the maximum potential dose in a single year, or the average individual dose over a longer period, thereby reflecting the kind of initial doubts that typically exist in developing a biosphere assessment. In practice, however, by more precisely defining the endpoint, it was found possible to justify a substantially simplified biosphere system description and model. This Example therefore provides a general indication of the importance of clearly identifying the basis on which biosphere modelling assumptions are made.

Although it is anticipated that each of the Reference Biospheres explored within BIOMASS Theme 1 should be a useful practical example, the quantitative results of the model calculations are not intended to be understood as prescribed biosphere ‘conversion factors’. In choosing to implement the ERB1A or ERB1B models, careful consideration would need to be given to their relevance (including associated data) to the particular assessment context at hand. Clearly, in the case of Example 1B, site specific information related to the likely configuration of the assumed release from the geosphere, the flow system within the aquifer, and the assumed relative location of the well, would promote a better understanding of the dispersion and interception of the released radionuclides. This, in turn, would help to provide more justification for quantitative measures of radiological impact.

Table A7 sets out the numerical results obtained using models for both variants of ERB1, providing indicators of potential radiological impact resulting from the postulated contamination of drinking water by a variety of radionuclides. The Table also highlights the main caveats that need to be observed in connection with the calculations. It is important to note that the units used to report the results for the two variants are necessarily different, reflecting the different configurations of the assumed geosphere/biosphere interface. Consequently, the two sets of indicators are not directly comparable.

### A3.3. THE AGRICULTURAL WELL (EXAMPLE REFERENCE BIOSPHERE 2A)

The first variant of BIOMASS Example Reference Biosphere 2 (ERB2A) was intended to address a range of multiple transfer and exposure pathways assuming ‘constant’ biosphere conditions. Part C, Section C3 sets out the basis for derivation of the resulting reference biosphere model, the numerical results, and the caveats that must be observed in connection with the calculations. Calculations were made for Tc-99, I-129, Nb-94 and Np-237.

TABLE A7. INPUT DATA AND CALCULATED INDICATORS OF RADIOLOGICAL IMPACT FOR EXAMPLE REFERENCE BIOSPHERE 1 (VARIANTS A AND B)

| Radionuclide | Consumption Rate ($m^3y^{-1}$) | Dose Coefficient ($Sv\ Bq^{-1}$) | ERB1A Dose ($Sv\ y^{-1}$ / $Bq\ m^{-3}$) | ERB1B 'Dilution Rate' ($m^3y^{-1}$) | ERB1B Dose ($Sv\ y^{-1}$ / $Bq\ y^{-1}$) |
|---|---|---|---|---|---|
| C-14 | 1.2 | 5.80E-10 | 6.96E-10 | 1.00E+04 | 6.96E-14 |
| Cl-36 | 1.2 | 9.30E-10 | 1.12E-09 | 1.00E+04 | 1.12E-13 |
| Ni-59 | 1.2 | 6.30E-11 | 7.56E-11 | 1.00E+04 | 7.56E-15 |
| Ni-63 | 1.2 | 1.50E-10 | 1.80E-10 | 1.00E+04 | 1.80E-14 |
| Se-79 | 1.2 | 2.90E-09 | 3.48E-09 | 1.00E+04 | 3.48E-13 |
| Sr-90* | 1.2 | 3.07E-08 | 3.68E-08 | 1.00E+04 | 3.68E-12 |
| Zr-93* | 1.2 | 1.22E-09 | 1.46E-09 | 1.00E+04 | 1.46E-13 |
| Nb-94 | 1.2 | 1.70E-09 | 2.04E-09 | 1.00E+04 | 2.04E-13 |
| Tc-99 | 1.2 | 6.40E-10 | 7.68E-10 | 1.00E+04 | 7.68E-14 |
| Pd-107 | 1.2 | 3.70E-11 | 4.44E-11 | 1.00E+04 | 4.44E-15 |
| Sn-126 | 1.2 | 4.70E-09 | 5.64E-09 | 1.00E+04 | 5.64E-13 |
| I-129 | 1.2 | 1.10E-07 | 1.32E-07 | 1.00E+04 | 1.32E-11 |
| Cs-135 | 1.2 | 2.00E-09 | 2.40E-09 | 1.00E+04 | 2.40E-13 |
| Cs-137 | 1.2 | 1.30E-08 | 1.56E-08 | 1.00E+04 | 1.56E-12 |
| Sm-151 | 1.2 | 9.80E-11 | 1.18E-10 | 1.00E+04 | 1.18E-14 |
| Ra-226* | 1.2 | 2.17E-06 | 2.61E-06 | 1.00E+04 | 2.61E-10 |
| Th-229* | 1.2 | 6.13E-07 | 7.36E-07 | 1.00E+04 | 7.36E-11 |
| Th-230 | 1.2 | 2.10E-07 | 2.52E-07 | 1.00E+04 | 2.52E-11 |
| Th-232* | 1.2 | 1.06E-06 | 1.27E-06 | 1.00E+04 | 1.27E-10 |
| Np-237* | 1.2 | 1.11E-07 | 1.33E-07 | 1.00E+04 | 1.33E-11 |
| Pa-231* | 1.2 | 1.92E-06 | 2.30E-06 | 1.00E+04 | 2.30E-10 |
| U-233 | 1.2 | 5.10E-08 | 6.12E-08 | 1.00E+04 | 6.12E-12 |
| U-234 | 1.2 | 4.90E-08 | 5.88E-08 | 1.00E+04 | 5.88E-12 |
| U-235* | 1.2 | 4.73E-08 | 5.68E-08 | 1.00E+04 | 5.68E-12 |
| U-236 | 1.2 | 4.70E-08 | 5.64E-08 | 1.00E+04 | 5.64E-12 |
| U-238* | 1.2 | 4.84E-08 | 5.81E-08 | 1.00E+04 | 5.81E-12 |
| Pu-238 | 1.2 | 2.30E-07 | 2.76E-07 | 1.00E+04 | 2.76E-11 |
| Pu-239 | 1.2 | 2.50E-07 | 3.00E-07 | 1.00E+04 | 3.00E-11 |
| Pu-240 | 1.2 | 2.50E-07 | 3.00E-07 | 1.00E+04 | 3.00E-11 |
| Pu-242 | 1.2 | 2.40E-07 | 2.88E-07 | 1.00E+04 | 2.88E-11 |
| Am-241 | 1.2 | 2.00E-07 | 2.40E-07 | 1.00E+04 | 2.40E-11 |
| Am-243* | 1.2 | 2.01E-07 | 2.41E-07 | 1.00E+04 | 2.41E-11 |
| Cm-245* | 1.2 | 2.15E-07 | 2.58E-07 | 1.00E+04 | 2.58E-11 |
| Cm-246 | 1.2 | 2.10E-07 | 2.52E-07 | 1.00E+04 | 2.52E-11 |

* indicates where relatively short lived daughters have been included in the calculations, by assuming they are in secular equilibrium with the parent; i.e. the dose coefficient listed includes the contributions from the progeny concerned.

Important Notes:

(1) 'Dose' values listed above should be interpreted solely as indicators of potential radiological impact arising from the postulated contamination and exposure route, described in the assessment context.
(2) The consumption rate is based on the annual consumption rate of water, assuming that all supplies are derived from the contaminated well source. No other exposure pathways are assumed.
(3) The dose coefficients are those applying to adult members of the public, from IAEA (1996)
(4) For Variant 1B, the 'dilution rate' is intended to be a realistic value, but has been arbitrarily selected (from a very wide range observed to have been used within deep repository performance assessments) at 10,000 $m^3\ y^{-1}$. The actual value used in a particular assessment would need to be justified according to the characteristics of the release to the aquifer, the aquifer itself and the well.

'Constant' in this case means that the characteristics of the biosphere system components are assumed to be invariant over the period in which contaminants released into the system achieve equilibrium concentration levels in environmental media. Since the delay from original disposal to the time when release may occur can be very long, and the subsequent release could occur over very extended periods, it is not clear that a constant biosphere based on present-day conditions at a particular site will be the most appropriate assumption. However, the identification of a range of constant biospheres, based on present-day analogue systems, could in principle form the basis for representing the most relevant alternatives that could arise within the time frame of interest. Indeed, such variants could find a collective role, for example, within assessment approaches based on a non-sequential representation of system change.

A much wider range of constant biosphere systems supporting consideration of multiple pathways, based on alternative assumptions regarding land use and/or mode of release, could, in principle, have been considered. However, it was not found possible to incorporate such cases within the timeframe of the BIOMASS Theme 1 programme.

During development of this Example the impacts of a number of alternative model assumptions on calculated doses were illustrated including the following:

(a) Alternative transfer pathways (e.g. consideration of sheep milk versus cow milk for $^{129}$I).
(b) Mathematical model variation (e.g. alternative representations of the effects of weathering of surface contamination on crops).
(c) Parameter value variation (e.g. correlated parameter variation in root uptake and $K_d$ for $^{99}$Tc).

As an example of the above, Table A8 compares the results from modelling the consumption of sheep milk with those for modelling the consumption of cow milk. For this calculation, all of the parameters associated with animal type and used in the calculation of $^{129}$I dose from consumption of animal produce were modified to be consistent with sheep. The human consumption rate of sheep milk was assumed to be the same as for cow milk, which is consistent with a livestock farming exposure group with a high consumption rate of milk. Note that this implies a very rich diet.

Figure A8 indicates the contributions to the $^{129}$I concentration of the milk at equilibrium due to the animal's consumption of water, fodder and soil and the inhalation of soil dust. The results show a seventeen fold increase in total dose from consumption of sheep milk compared to that from consumption of cow milk.

The maximum dose to the livestock farming exposure group across all exposure pathways for $^{129}$I is approximately 5E-7 Sv y$^{-1}$. The increase of approximately 1E-6 Sv y$^{-1}$ illustrated in Table A8 could lead to a substantial increase in total dose were sheep to be considered instead of cows. However this effect would be reduced were the human consumption rates adjusted to reflect the higher calorific content of sheep milk compared with cow milk.

Results for ERB2A are discussed in Section A4 and the detail of important modelling of processes and data for parameters is given in Part C. Figure A9 illustrates application of the ERB2A results to a time-dependent source term using linear interpolation between specified concentration values. In this case the source term used was output from groundwater modelling calculations provided by EPRI (Kessler et al., 2000). It is of interest to note that the results for all of the exposure groups lie approximately within an order of magnitude.

TABLE A8. SENSITIVITY OF ERB2A TO VARIATIONS IN $^{129}$I TRANSFER TO MILK

| | Cow milk | Sheep milk |
|---|---|---|
| Peak concentration in milk, (Bq kg$^{-1}$ fresh weight) | 8.91E-4 | 1.49E-2 |
| Peak $^{129}$I dose from consumption of milk (Sv y$^{-1}$) | 7.26E-8 | 1.22E-6 |

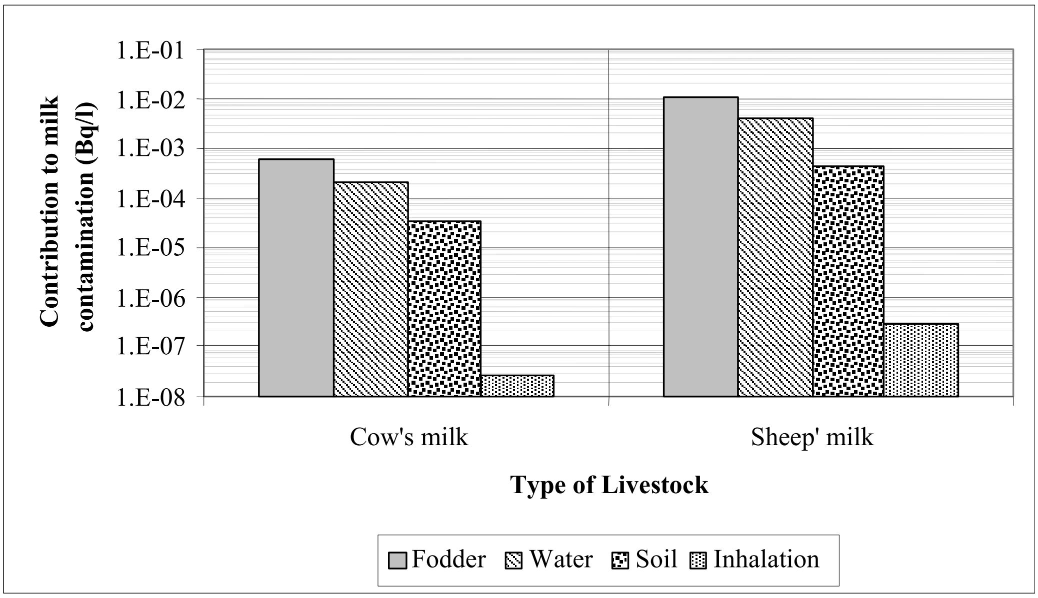


*FIG. A8. Breakdown of $^{129}$I concentration of milk depending on the source of contamination at equilibrium.*

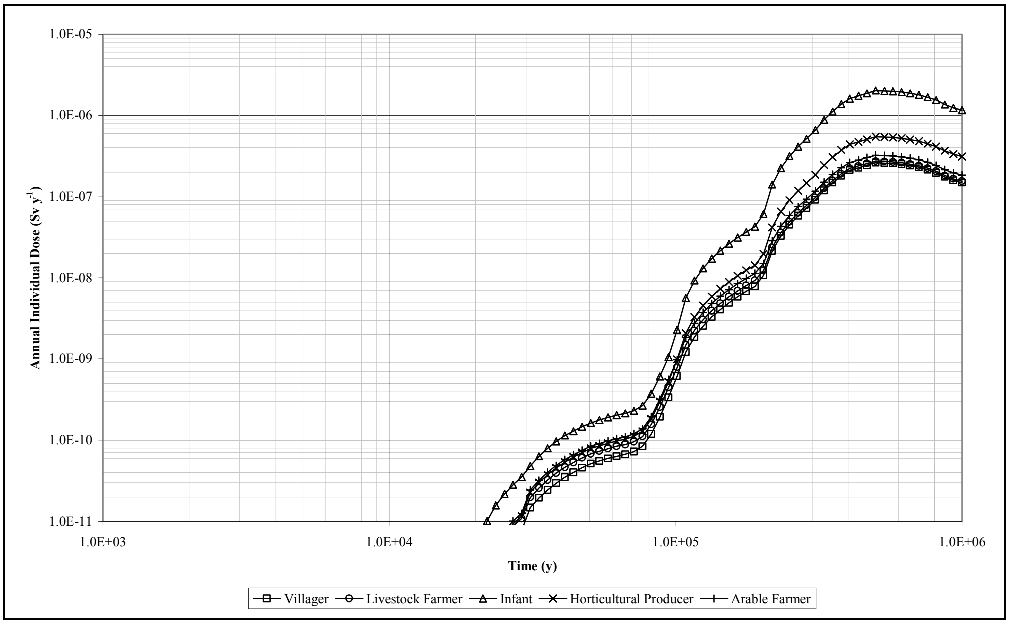


*FIG. A9. Total annual individual effective doses for ERB2A calculated using a realistic assessment based source term.*

A3.4. NATURAL RELEASE OF CONTAMINATED GROUNDWATER TO THE SURFACE ENVIRONMENT (EXAMPLE REFERENCE BIOSPHERE 2B)

The second variant of Example Reference Biosphere 2 (ERB2B) was designed to investigate the relative significance of alternative geosphere-biosphere interfaces. Part C (Section C4) sets out the basis for derivation of the resulting reference biosphere model, the numerical results, and the caveats that apply in connection with the calculations.

In this Example, the system identification part of the Methodology led to the definition of a number of types of habitat according to their interaction with the aquifer (Figure A10). Model development involved construction of IMs for each of the identified habitats as well as for interactions between them.

Table A9 provides a comparison of the radionuclide transfer rates due to detritus movement and erosion for this Example. It shows that, given the current mathematical representation of these processes, the transfer of radionuclides due to the movement of detritus from the arable, grassland and shrubland habitats to the local watercourse is significantly greater than that for erosion (by more than 3 orders of magnitude). The transfers are approximately equal for $^{129}$I, $^{237}$Np and $^{94}$Nb from the wetland areas. Due to the greater significance of detritus transfer, the erosion transfer was ignored from the arable, grassland and shrubland habitats, whereas both the detritus and erosion transfers were included from the wetland habitat. However, the original calculational basis and results are retained in Part C (Section C4) as an example of how preliminary/side calculations can be used to simplify the model and reduce the burden on data requirements.

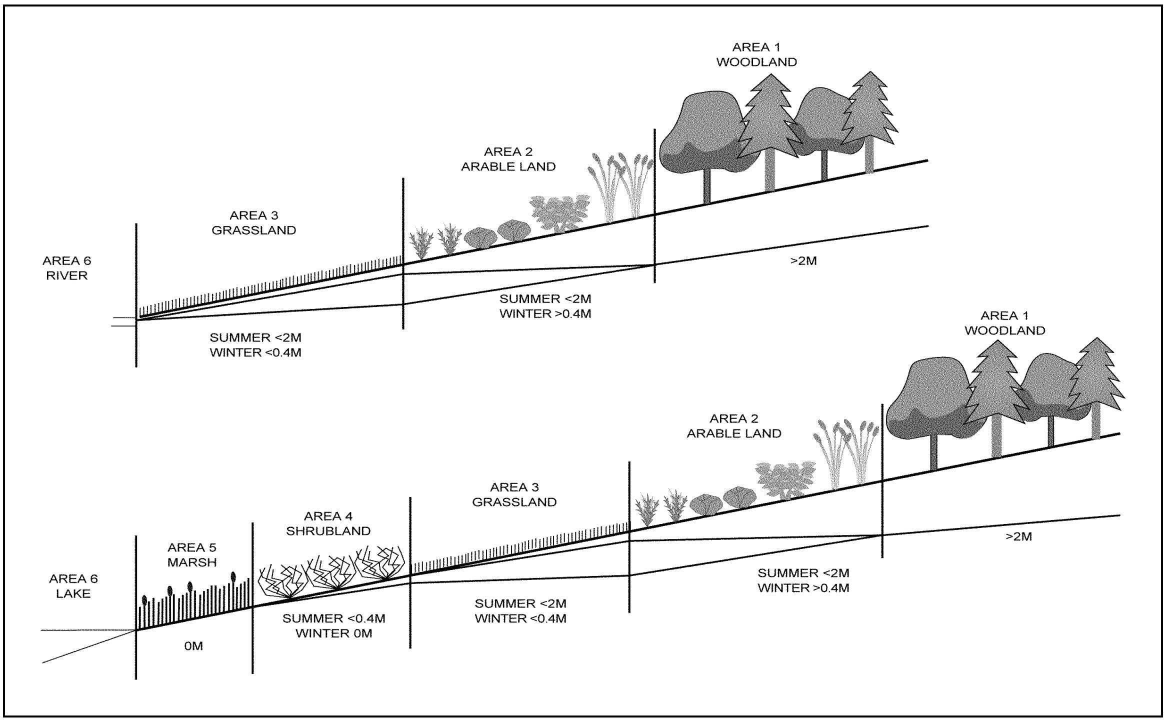


*FIG. A10. Cross sections across upstream and downstream region of Example Reference Biosphere 2B. The lines under the land surface show the groundwater level in summer and winter (figures are metres).*

TABLE A9. RATIO OF THE DETRITUS TRANSFER RATE TO THE EROSION TRANSFER RATE

| From | Detritus Transfer Rate: Erosion Transfer Rate | | | |
|---|---|---|---|---|
| | $^{129}I$ | $^{237}Np$ | $^{99}Tc$ | $^{94}Nb$ |
| Arable land | 1.4E+08 | 2.4E+08 | 4.5E+11 | 2.7E+07 |
| Grassland | 7.8E+05 | 1.1E+06 | 1.6E+09 | 3.7E+05 |
| Shrubland | 1.0E+04 | 2.1E+04 | 2.4E+07 | 2.1E+03 |
| Wetland | 9.5E-01 | 2.0E+00 | 1.4E+03 | 2.0E-01 |

Additional results are provided in Part C (Section C4) assuming that the aquifer is contaminated only under each habitat area but still allowing radionuclides to spread from one habitat to another (through manuring for example). This allows the significance of different features and processes to be examined.

Six candidate critical groups were considered in this Example: arable farmer, livestock farmer, horticulturist, gamekeeper, fisherman and villager. These groups respectively ingest arable products, animal products, fruit and vegetable products, wild (i.e. undomesticated) foods, and fish at around the upper 97.5 percentile values; the villager represents an average consumer. As expected, calculated doses mostly arise from ingestion of food. The differences between the candidate critical groups in terms of the total calculated doses were relatively small. In no case did the calculated dose to the critical group exceed that to the villager by more than a factor of four. This fairly small difference reflects the fact all the candidate critical groups were assumed to ingest only contaminated food. The differences between the groups is then mostly determined by the relative proportions of the various types of food eaten and the different habitats from where they are derived.

For all the candidate critical groups the main exposure pathways contributing to calculated dose from $^{129}I$ are wild vegetal products; this contributes between 50 and 80% of the total calculated dose, depending upon which candidate critical group is being considered. Other important exposure pathways are cattle products, fish, and wild animal products. These four pathways contribute to more than 95% of total estimated dose. The main exposure pathways contributing to calculated dose from $^{237}Np$ are wild vegetal products (80%), dust inhalation from shrubland and wetland (15%) and soil consumption from shrubland and wetland (4%). The main exposure pathways contributing to total calculated dose from $^{99}Tc$ are wild vegetal products (90-92%) and wild meat (5-7%). There also appears to be little difference in calculated dose from $^{99}Tc$ between the various candidate critical groups. For $^{94}Nb$, external irradiation from soil represents the primary contribution to total dose, 96-99%, depending on candidate critical group.

The dominance of wild vegetal products amongst the contributions to total dose indicates that even relatively small consumption of foods taken from the shrubland and wetland can give rise to significant contributions to dose. This arises from two effects. The first is the greater contamination of these down-slope habitats due to their proximity to the contaminated groundwater. The second is the rather conservative assumptions that were made, in the absence of experimental data, regarding the uptake of these radionuclides by fungi.

Part C (Section C5) provides a full range of results for the whole system, for discharges through individual geosphere-biosphere interfaces into each habitat, for each exposure pathway and for each exposure group. When applied to an assessment source term, the absolute significance of the results can be determined and then the quality of the justification for the more significant data can be re-examined.

### A3.5. BIOSPHERE CHANGE

The purpose of this Example was to investigate the implications of dealing with change(s) in the biosphere system. The overall level of ambition in developing this Example was not the same as in the other Examples. It was not the aim to follow the complete Methodology through to the calculation of individual doses. Instead, the goals were limited to an analysis of how change can be considered, and to reflecting on the value of such approaches in providing an adequate representation of potential radiological impact in future environmental conditions.

Part C (Section C5) provides a description of the global factors that can influence environmental change at the regional and local scales e.g. global climate change, earth processes and meteorite impacts, and social/institutional developments.

The particular focus of this Example was to demonstrate the scheme developed as part of the BIOMASS Methodology for considering the implications of changes that may occur within the biosphere system during the period in which a release from the disposal facility could occur. Illustrations are provided of the implementation of the approach, which allows changes in climate and landscape to be factored into the safety assessments for a particular facility. Three cases were examined, based on available information relating to previous studies, including demonstration performance assessments for hypothetical disposal facilities at Aspö (Sweden) and Harwell (UK). The third case applied to a generic site context, i.e. that assumed for ERB2A, and explored the general implications of a particular global climate sequence. The results can be used to determine the potential significance of limiting consideration to a constant biosphere, as was the case in ERB2A.

## A4. DISCUSSION

BIOMASS Theme 1 successfully addressed both the subject of a methodology for developing biosphere models for application to waste disposal assessment (assessment biospheres) and the development of Example Reference Biospheres. In constructing the Example Reference Biospheres it was always found to be possible to reach a consensus view on what it was reasonable and justifiable to include and exclude in a conceptual model. More problematic was the question of data where, in the absence of site specific information, it was sometimes found to be difficult to decide on the value that a parameter should have. The most important example of this was the question of aquifer flow in Example 1B, recognising that the model causes the calculated doses to scale directly with the degree of dilution (and therefore the flow within the aquifer, through which the radionuclide release was uniformly distributed). The aquifer flow was set at 10,000 cubic metres per year, which was considered to be reasonable but this assumption needs to be taken into account in applying the ERB1B results, since the range of reasonable values is large.

BIOMASS Theme 1 demonstrated the practicality of developing reference biospheres for specific applications. Such reference biospheres are a useful addition to the radioactive waste disposal assessment “tool kit” but should be applied with caution in conditions which may conflict with the components of the original reference assessment context. Work within BIOMASS Theme 1 further demonstrated the importance of building a self-consistent assessment context as a start point for constructing a biosphere model than can later be demonstrated to be fit for purpose.

In the context of total performance assessment, the biosphere may be more than simply the receptor in which radiological impacts of future releases will be expressed. Certain features of the biosphere, and processes occurring within the biosphere, also serve to establish boundary conditions for groundwater flow and transport and can thereby influence the long term performance of the disposal system. Reference biospheres that are adopted for the purpose of evaluating indicators of radiological impact will not necessarily be appropriate to characterising the dynamics of releases from the geosphere, their location and extent. Nevertheless, it is important to ensure that consistency is achieved in the approach to representing biosphere systems across the performance assessment as a whole.

Development of biosphere models for application to radioactive waste disposal assessment is an iterative process. Using the BIOMASS Methodology to create the Example Reference Biospheres required inputs from various groups at different stages and could not be completed effectively by different groups working in isolation. This was particularly the case for activities involving consideration of exposure groups and for activities involving data derivation. In some cases the process of derivation of data led to proposed changes in the mathematical models, the impacts of which on assessment endpoints had to be evaluated.

The development of a suitable audit trail is a fundamental element of each stage of the model development process. This enables lessons learned in applying the model and interpreting its results to be used to revisit assumptions and decisions. Such information may also be used to refine the model, perhaps by identifying particularly important FEPs or sensitive parameters. A systematic methodology provides an approach for incorporating new information into biosphere assessments, taking account of experience from using the models, changing assessment contexts, new scientific understanding and evolving regulatory requirements. Illustrations have been provided of the iterative approach to model development and to give examples given of the process of documenting assessment decisions in the light of side calculations.

Example Reference Biosphere 1 can be considered as a useful ‘yardstick’ especially when there is no biosphere capability and the only information available is the calculated concentrations of radionuclides in groundwater. However it is unlikely to address sufficient potential exposure pathways to satisfy all stakeholders. Example Reference Biosphere 2 is sufficiently generic to be useful as a yardstick for a number of assessment contexts and conditions, and addresses a wider range of pathways than does ERB1. The results obtained showed that drinking water does not always represent the worst case and, for important radionuclides, provide an indication of the extent to which other pathways could dominate over drinking water.

Example Reference Biosphere 2B provides an indication of the importance of geosphere-biosphere interfaces other than a well. However it is clear that the extent of any such differences will be dependent on local near-surface hydrogeology which cannot be specified generically. Since the results for ERB2B rely on unit concentrations in the aquifer, they can be compared directly with those for the agricultural well scenario in ERB2A. Note that the source term from below in ERB2B corresponds to a groundwater influx ranging from 0.1 m $y^{-1}$ to 0.4 m $y^{-1}$ (depending on habitat), the inflow from irrigation in ERB2A corresponds to 0.2 m $y^{-1}$. That is, the volume of contaminated water (and hence activity) entering the biosphere per unit area is about the same in both cases.

Table A10 provides a summary of the BIOMASS Theme 1 Example Reference Biosphere results normalised to unit concentration of radionuclides in groundwater.

TABLE A10. SUMMARY OF BIOMASS THEME 1 EXAMPLE REFERENCE BIOSPHERE RESULTS
(The Table shows calculated doses (Sv/y) for each candidate critical group)

| Radionuclide | Example | Pathway/Habitat | Arable Farmer | Livestock Farmer | Horticulture | Gamekeeper | Fisherman | Villager |
|---|---|---|---|---|---|---|---|---|
| I-129 | 1A | Drinking water | 1.3E-07 | | | | | |
| | 2A | Drinking water | 1.3E-07 | 1.3E-07 | 1.3E-07 | | | 6.6E-08 |
| | | Total | 7.2E-07 | 4.9E-07 | 6.8E-07 | | | 3.6E-07 |
| | 2B | Arable | 7.9E-10 | 1.5E-09 | 7.8E-10 | 1.0E-09 | 1.2E-09 | 7.6E-10 |
| | | Grassland | 3.2E-09 | 3.9E-09 | 3.2E-09 | 8.5E-09 | 3.7E-09 | 3.2E-09 |
| | | Shrubland | 4.0E-09 | 4.3E-09 | 4.0E-09 | 1.2E-08 | 4.3E-09 | 3.9E-09 |
| | | Wetland | 5.0E-10 | 7.1E-10 | 4.9E-10 | 1.4E-09 | 7.1E-10 | 4.9E-10 |
| | | River lake | 1.1E-10 | 1.4E-10 | 9.7E-11 | 1.1E-10 | 1.8E-10 | 8.3E-11 |
| | | Total | 8.6E-09 | 1.1E-08 | 8.6E-09 | 2.3E-08 | 1.0E-08 | 8.4E-09 |
| Np-237 | 1A | Drinking water | 1.3E-07 | | | | | |
| | 2A | Drinking water | 1.3E-07 | 1.3E-07 | 1.3E-07 | | | 6.6E-08 |
| | | Total | 4.4E-07 | 3.7E-07 | 7.7E-07 | | | 2.9E-07 |
| | 2B | Arable | 1.5E-09 | 2.2E-09 | 1.5E-09 | 3.7E-09 | 1.8E-09 | 1.3E-09 |
| | | Grassland | 2.3E-08 | 2.3E-08 | 2.3E-08 | 6.8E-08 | 2.3E-08 | 2.3E-08 |
| | | Shrubland | 3.2E-08 | 3.2E-08 | 3.2E-08 | 9.7E-08 | 3.2E-08 | 3.2E-08 |
| | | Wetland | 1.4E-08 | 1.4E-08 | 1.4E-08 | 7.7E-08 | 1.4E-08 | 1.4E-08 |
| | | River lake | 4.9E-10 | 3.2E-10 | 4.8E-10 | 1.0E-09 | 1.2E-09 | 3.1E-10 |
| | | Total | 7.1E-08 | 7.2E-08 | 7.1E-08 | 2.5E-07 | 7.2E-08 | 7.1E-08 |
| Tc-99 | 1A | Drinking water | 7.7E-10 | | | | | |
| | 2A | Drinking water | 7.7E-10 | 7.7E-10 | 7.7E-10 | | | 3.8E-10 |
| | | Total | 4.2E-09 | 3.6E-09 | 3.9E-09 | | | 2.2E-09 |
| | 2B | Arable | 1.7E-10 | 2.2E-10 | 1.6E-10 | 4.1E-10 | 1.6E-10 | 1.6E-10 |
| | | Grassland | 2.7E-09 | 2.7E-09 | 2.7E-09 | 8.1E-09 | 2.7E-09 | 2.7E-09 |
| | | Shrubland | 3.8E-09 | 3.8E-09 | 3.8E-09 | 1.2E-08 | 3.8E-09 | 3.8E-09 |
| | | Wetland | 1.9E-10 | 1.9E-10 | 1.9E-10 | 7.6E-10 | 1.9E-10 | 1.9E-10 |
| | | River lake | 5.9E-12 | 5.0E-12 | 5.1E-12 | 9.4E-10 | 4.4E-12 | 4.1E-12 |
| | | Total | 6.9E-09 | 6.9E-09 | 6.9E-09 | 2.2E-08 | 6.9E-09 | 6.9E-09 |
| Nb-94 | 1A | Drinking water | 2.0E-09 | | | | | |
| | 2A | Drinking water | 2.0E-09 | 2.0E-09 | 2.0E-09 | | | 1.0E-09 |
| | | Total | 1.7E-06 | 1.7E-06 | 1.7E-06 | | | 1.7E-06 |
| | 2B | Arable | 7.5E-08 | 1.3E-07 | 7.5E-08 | 6.5E-08 | 1.6E-07 | 7.5E-08 |
| | | Grassland | 2.0E-07 | 2.2E-07 | 2.0E-07 | 4.9E-07 | 2.9E-07 | 2.0E-07 |
| | | Shrubland | 2.7E-07 | 2.4E-07 | 2.7E-07 | 7.5E-07 | 3.3E-07 | 2.7E-07 |
| | | Wetland | 2.5E-07 | 2.3E-07 | 2.5E-07 | 7.4E-07 | 2.9E-07 | 2.5E-07 |
| | | River lake | 2.0E-08 | 8.1E-09 | 2.0E-08 | 1.4E-08 | 5.0E-08 | 2.0E-08 |
| | | Total | 8.2E-07 | 8.3E-07 | 8.2E-07 | 2.1E-06 | 1.1E-06 | 8.2E-07 |

**Notes:**

For Example 1A: Drinking water pathway only, one consumption rate.

For Example 2A: Each exposure group is assumed to drink the same water as for Example 1A, but at different consumption rates.

For Example 2B: Results are presented separately for the proportion of the total release into each habitat. No drinking water pathway included. If water were taken from a well, the results would be as for Examples 1A or 2A. If water were taken from the river or lake, the drinking water dose would be lower because of dilution.

The $^{129}I$ exposure group doses from the agricultural well scenario (ERB2A) are consistently one to two orders of magnitude higher than those for ERB2B. A comparison of the $^{99}Tc$ exposure group doses shows the Example 2A doses to be higher except for the pathways associated with the semi-natural areas of the Example 2B system. The assumed high transfer factor to fungi means that this pathway dominates the exposure group doses in Example 2B and these doses are similar to the exposure groups doses for Example 2A. The results for $^{237}Np$ show that doses from some individual exposure pathways in the Example 2B system are higher than those in the Example 2A system, but that the overall Example 2B exposure group doses are lower than for Example 2A. The difference is not large. The $^{94}Nb$ doses for the Example 2B system are mostly lower than those for Example 2A; however the high occupancy of contaminated semi-natural areas by the gamekeeper exposure group in Example 2B means that the highest doses for Examples 2A and 2B are similar.

## A5. ISSUES FOR THE FUTURE

In providing a generic methodology for defining assessment biospheres for application to radioactive waste disposal assessment, BIOMASS Theme 1 has raised the question of ‘fitness for purpose’ with respect to biosphere modelling. An evaluation of the key processes, interactions and dominant uncertainties and biases from each of the BIOMASS Examples Reference Biospheres might lead to further development and enhancement of the Methodology and might help to guide questions relating to fitness for purpose. There is a need to understand the extent of inherent variability in processes affecting radionuclides in the biosphere and to balance this understanding against resource allocations for model and data derivation.

It is generally accepted that, during the course of release of radionuclides from a radioactive waste repository, the biosphere will change. BIOMASS Theme 1 considered the consequences of major changes e.g. in climate but there are other processes and events that act on a shorter time scale. Further work on the effects of climate change forms part of a research and development programme funded by the European Commission (BIOCLIM) which will consider the need to evaluate the consequences of shorter term events, such as those that could occur during the transition from one climate state to another or even within a single climate state.

BIOMASS has further demonstrated the need for an international list of FEPs relating to the biosphere both during model construction and when considering fitness for purpose. The existing international FEP list (developed within the context of BIOMOVS II) needs to be maintained and developed as a basis for future biosphere modelling activities and the generation of additional reference biospheres.

There is a significant literature on environmental risk assessment in the context of non-radioactive contaminants. BIOMASS has concentrated on radionuclides in the context of radioactive waste disposal assessment. There would be merit in both comparing and contrasting approaches taken to radioactive and non-radioactive contaminants, as well as in exploring the opportunities for applying the methods developed within BIOMASS to other areas of radiological protection.

# A6. CONCLUSIONS

## A6.1. BIOMASS METHODOLOGY

A methodology (the BIOMASS 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.”*

The BIOMASS 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, notably in ICRP Publication-81 (ICRP, 1998).

The BIOMASS Methodology builds on and demonstrates how to implement guidance on hypothetical critical groups and biospheres in the context of solid radioactive waste disposal already developed within the International Atomic Energy Agency, notably through IAEA-TECDOC-1077 (IAEA, 1999).

The main steps in the BIOMASS Methodology are:

(a) development and confirmation of the assessment context;

(b) biosphere system identification and justification;

(c) biosphere system description;

(d) identification of representative exposed population groups, including hypothetical critical groups;

(e) conceptual and mathematical model development for radionuclide migration and accumulation, and consequent radiation exposures;

(f) calculation of assessment endpoints (e.g. doses) and confirmation, normally by iteration of some or all of the above steps, of the characteristics of the hypothetical critical groups.

The importance of a clear assessment context, to clarify intentions and support a coherent biosphere assessment process within an overall repository performance assessment, is strongly emphasised. A well described assessment context is an important tool for ensuring consistency across the performance assessment as a whole.

The BIOMASS Methodology provides a systematic approach to decision making, including decisions on how to address biosphere change. This should help to ensure consistency and completeness when constructing assessment biospheres. Combined with careful record keeping, this should also provide a clear audit trail, which is especially important given the complications that arise from the need for iteration within the steps of the Methodology.

In working through the successive steps of the BIOMASS Methodology it is found useful to construct and employ two schemes. The first is used to categorise the principal components of the biosphere system i.e. climate, soil, etc., to help identify the type of biosphere system that was to be modelled. The second scheme is used to characterise the principal components, i.e. to specify them in greater detail, so that the biosphere system can be adequately described. It is envisaged that others will find these schemes helpful, especially when constructing assessment biospheres on the basis of environmental analogues for landscape, climate, human community etc. These schemes are set out in a series of tables to facilitate their application.

The international list of biosphere features, events and processes (FEPs), developed originally in BIOMOVS II, is found to be useful in checking that potentially relevant FEPs had been taken into account within the assessment biosphere. Some restructuring of the FEP List has been carried out to facilitate this. Future users of the FEP List should also consider the need for maintenance.

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.

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. Data selection is found to put high demands on resources. Development of mathematical models within BIOMASS Theme 1 highlighted the close interactions between these models and the extent and form of the available data.

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 but this application has yet to be tested. 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.

## A6.2. EXAMPLES

The BIOMASS 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 modelling 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.

The set of example assessment contexts is chosen to be as widely relevant as possible, taking into account diverse regulatory requirements and the interests of different assessment groups. The examples are:

- *Example 1A:* a drinking water well under constant biosphere conditions with unit concentration in the aquifer supplying the well;
- *Example 1B:* a drinking water well under constant biosphere conditions with unit activity 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.

The results have been used to explore the extent to which internationally defined and agreed assessment biospheres might be viewed as points of reference, i.e. 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:

(a) Examples 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;

(b) 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 (i.e. dose per unit concentration in groundwater) are sufficiently well justified to allow their use as indicators of potential radiological impact. The results for the many radionuclides included in Example 1A are considered to be very widely relevant, since ingestion exposure from a drinking water well is commonly considered in repository performance assessments. The Example 2A results for Tc-99, I-129, Nb-94 and Np-237 are relevant to agricultural use of well water in a temperate climate;

(c) 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.

In addition, the output from these examples may be useful to other assessments by, for example, indicating the possible level of significance of potentially relevant features, events and processes. Side calculations demonstrate how it is possible to determine when sufficient sub-division of processes has been provided to meet the requirements of the assessment context.

As intended, the three numerical examples display significant differences, particularly with respect to:

(a) the radionuclide transfer pathways;

(b) the exposure pathways;

(c) the characteristics of the hypothetical critical groups.

The examples provide important information on other issues pertaining to radionuclide transfer and exposure pathways:

(a) the significance of release to the biosphere via well abstraction compared to releases from various natural groundwater flow paths;

(b) the significance of semi-natural habitats compared to agricultural habitats, as well as radionuclide transfers between habitats and associated radiation exposure pathways;

(c) the importance of radionuclide properties in determining critical exposure pathways and dose;

(d) the relative significance of alternative assumptions for exposure groups in a wide variety of exposure circumstances.

Calculations are carried out for Example 1 ('drinking water well' pathway) for a very wide range of radionuclides. Calculated dose values for the different radionuclides span five orders of magnitude, reflecting their different radio-toxicities. The results for Example 1B highlight the influence of dilution processes at the geosphere-biosphere interface.

For Examples 2A and 2B results are determined assuming unit concentrations of four radionuclides in groundwater: I-129, Np-237, Tc-99 and Nb-94. These four radionuclides are 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 are 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 reveals that:

(a) ingestion exposures from irrigated agricultural land (Example 2A) are about five times higher than from drinking water alone (Example 1A); for Nb-94 the external irradiation doses are very much higher than those due to ingestion. This leads to the conclusion that consideration of the drinking water pathway alone may result in underestimation of the critical group doses;

(b) ingestion exposures for the natural discharge example (Example 2B) are within an order of magnitude of those for the irrigated agricultural land example (2A);

(c) in the natural discharge example (2B), exposures due to ingestion of undomesticated or uncultivated foods are significant. In part at least, this may be because lack of data (on radionuclide uptake factors for fungi for example) makes it necessary to adopt a cautious approach;

(d) for the four radionuclides that are considered in all the Examples, the doses to the various candidate critical groups vary by less than a factor of four.

The trial examples (Example 3) are 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 BIOMASS 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 effects of climate change are addressed through consideration of discrete, unconnected biosphere states. For two consecutive time periods within the generic case, however, consideration is also given to an approach in which the distribution of radionuclide changes as the biosphere system itself changes (with climate for example). The issue of biosphere change was not explored quantitatively however.

Biosphere change in Example 3 has been tested primarily for global climate change, although the BIOMASS Methodology allows for a full range of 'external FEPs' (e.g. climate change and, in response to this, sea level change, ice sheet development etc.) to be considered systematically in relation to their potential impact upon the biosphere system.

# REFERENCES TO PART A


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# PART B

## BIOMASS METHODOLOGY FOR CREATING ASSESSMENT AND REFERENCE BIOSPHERES

# B1. INTRODUCTION

## B1.1. BACKGROUND

The application of radiological protection objectives in the context of the safety performance of geological disposal systems for solid radioactive waste has customarily 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. Hence the biosphere (where radiation exposures are usually assumed to be incurred) is an essential part of the overall disposal system to be assessed, and the evaluation of potential radiological impacts is an integral part of post-closure safety assessment.

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 the future 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, many hundreds or thousands of years after repository closure.

Any description of the biosphere used in a long-term performance assessment could therefore appear somewhat arbitrary. A choice of assumptions has to be made as the basis for such an assessment; taken together, however, these choices must be consistent with the aim of providing a robust, yet reasonable level of assurance regarding the acceptability of possible future releases from a repository, through the geosphere and into the biosphere. The function of the biosphere(s) adopted for the purpose of assessing system performance is therefore to act as a form of 'measuring instrument' for evaluating representative indicators of the potential radiological impact of the repository. When integrated with understanding arising from assessments of the behaviour of the disposal system as a whole, such indicators can provide an input to decisions regarding the acceptability of long-term system performance. As such, they must be sufficiently representative to provide a suitable degree of assurance, consistent with overall performance assessment objectives.

Thus, at the start of BIOMASS Theme 1 a need was recognised, in the context of individual national programmes for solid radioactive waste disposal, to provide detailed guidance on assumptions appropriate to the development of assessment biospheres used to build confidence in long-term safety cases for repositories. There was also general interest in exploring the extent to which internationally defined and agreed Reference Biosphere(s) might be viewed as "international standard measuring instrument(s)". Guidance on the definition and potential limitations of such internationally agreed measuring instruments was of great interest to all concerned.

BIOMASS Theme 1 has developed and applied a consistent approach for identifying the assumptions and hypotheses relevant to the definition of biospheres for practical radiological assessment of releases in the long term. The primary goals of the programme were first to develop a methodology for the creation of assessment biospheres (in general) and reference biospheres (in particular) that could be applied to a wide range of purposes. Second, to use this methodology (the BIOMASS Methodology) to produce a series of example Reference Biospheres that can provide a useful point of reference as broadly applicable indicators of potential radiological impact for radionuclide releases occurring in the long term. For some applications, such Reference Biospheres may be sufficient to meet the needs of a particular assessment. Nevertheless, it is recognised that different assessments have different purposes and that different levels of details and/or different types of complexity may be required to build confidence in the overall performance assessment.

It should be noted that the focus of activity within BIOMASS Theme 1 was restricted to safety indicators for radionuclides released via groundwater. Alternative pathways for radionuclides to reach the accessible environment, including human intrusion and gas transport, will ultimately need to be addressed in a consistent fashion.

### B1.2. STRATEGY FOR IMPLEMENTATION OF THE REFERENCE BIOSPHERE CONCEPT

The methodological framework for the development of Reference Biospheres was discussed within Theme 1 and was reported in the Annex to Theme 1 Working Document No. 1 (IAEA, 1999). This work followed on from ideas developed in BIOMOVS II (1996) and is expressed diagrammatically in Figure B1.

Generally speaking, the broader the context in which an assessment biosphere is designed to be applied, the simpler it is likely to be. A Reference Biosphere that is applicable to a wide range of circumstances will tend to be one that involves fewer and less complex assumptions regarding the geosphere/biosphere interface, biosphere constituents and time dependence, as well as potential exposure pathways. However, it also follows that it will be less capable of addressing in detail all issues of potential concern. Conversely, Reference Biospheres that explicitly incorporate more complex considerations will tend to be restricted to a narrower range of applications. However, special issues (e.g. site-specific considerations) of interest in that particular situation can then be more fully addressed.

The biosphere itself is very complex, but it would not necessarily be sensible to develop very detailed representations for the long-term future, as such complexity would tend to imply an unwarranted precision. However, simpler models are potentially more difficult to defend because they may not explicitly address important processes. Demonstrating fitness for purpose entails striking an acceptable balance between the level of complexity and the defensibility of the approach that is adopted, taking into account the particular context in which it will be used.

One example of a simplified approach (drinking water pathway from well abstraction – independent of climate) is that which has been developed in Finland (Vieno, 1994). A stylised biosphere presentation (Barrdahl, 1996), incorporating a broader spectrum of exposure pathways, was also employed in the Swedish Nuclear Safety Inspectorate’s SITE 94 performance assessment (SKI, 1996). This assessment was designed to emphasise the site evaluation in view of the behaviour of the geological barrier and also performance assessment methodology and canister integrity.

The strategy for implementation of the Reference Biosphere concept within BIOMASS Theme 1 was to consider a series of example assessment contexts that draw increasingly on the need for more complex considerations. Starting with a simple example (e.g. dose calculation for drinking water only, taken from a well source in constant climate conditions), consideration was next given to additional biosphere constituents and exposure pathways (e.g. well water used for irrigation of crops and watering livestock) and alternative geosphere/biosphere interfaces, but still within constant biosphere conditions. Then, examples were considered dealing with changing biosphere systems.

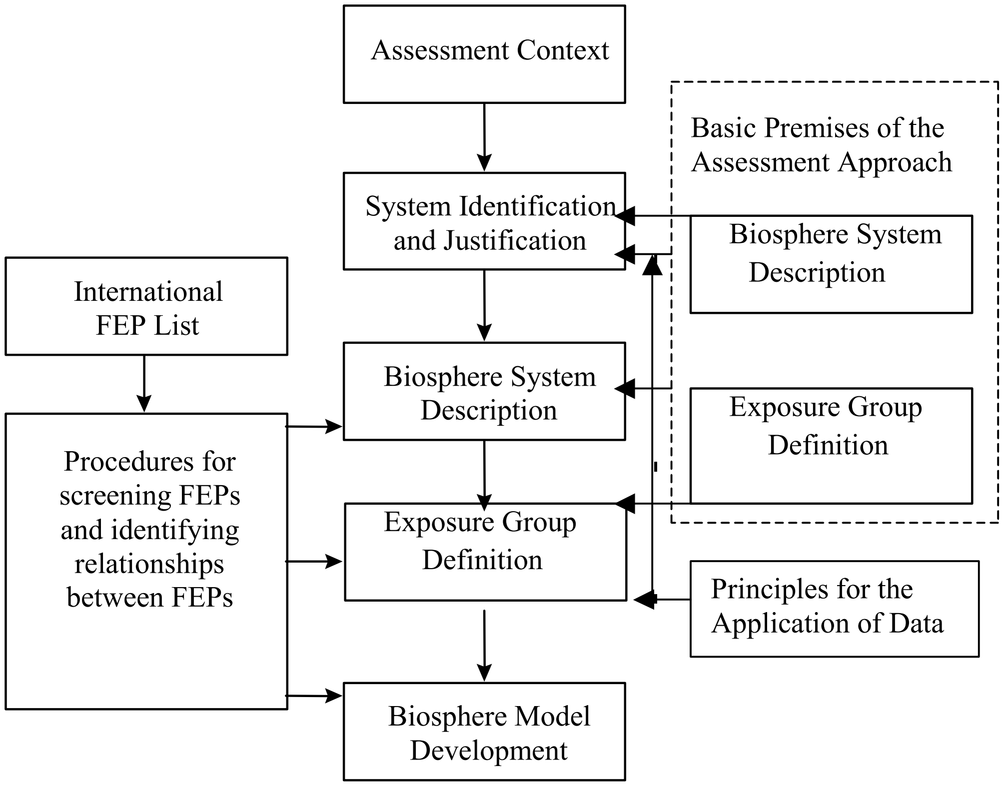


*FIG. B1. Schematic Illustration of the BIOMASS Methodology.*

Some primary principles for the development of coherent biosphere system descriptions were outlined in the original work of BIOMOVS II (1996) dealing with development of a Reference Biosphere Methodology. There, the 'Basic System Description' was defined as:

> *"... the reference biosphere system ... of interest [which] expresses the assumed foundation for long-term representation of the biosphere; in principle, it should, as far as possible, be considered independently of any potential radionuclide input. This means characterising future representative biospheres in terms of their spatial domain, the ecosystems they are assumed to incorporate (including the part played by human communities) and their system dynamics."*

Development of the Reference Biosphere Methodology into the BIOMASS Methodology has identified the biosphere system description as a key part of any systematic approach for the development and justification of biosphere models created to support long-term safety assessments for radioactive waste disposal. Here, to differentiate more general biosphere models from the Reference Biospheres developed in the BIOMASS project, we call them "assessment biospheres" defining an assessment biosphere as:

> *"the set of assumptions and hypotheses that is necessary to provide a consistent basis for calculations of the radiological impact arising from long-term releases of repository-derived radionuclides into the biosphere."*

The aim is to provide a biosphere system description that includes those aspects of the biosphere that are pertinent to the development of a conceptual model for specified radiological assessment purposes whilst taking into account the interdependence between human communities and their surrounding environment. When doing this it is important to ensure self consistency in the biosphere system description.

Basic assumptions (effectively adopted as part of the overall assessment context) regarding the types of society to be considered, human community structures and level of technological development are fundamental to decisions made regarding the definition of future biosphere systems, as well as to the definition of potential exposed groups. For example, the assumption of a small farming community, substantially dependent on local produce, would invoke a significantly different approach from that relevant to a large-scale commercial farming enterprise, both in terms of the diversity of the biosphere system and the potential radiation exposure pathways to be considered. Inevitably, when such basic assumptions are made, they need to take into account a general understanding of the comparative radiological significance of different types of environment and different modes of biosphere resource exploitation.

At the same time, assumptions regarding human society need to be consistent with fundamental considerations of climate, landscape and ecology. A general understanding of past and present biosphere conditions (ecological and palaeoecological studies) can offer coherence to, and scientific justification for, the various assumptions and hypotheses that need to be made in a specific assessment context. For any given (or assumed) landscape, the environmental components and systems of exchange – whether natural or semi-natural, agricultural, urban or industrial – should also be consistent with the assumed topographical and hydrological regime, taking into account climate and potential human influences.

For long-term releases, it is expected that climate and natural geomorphological processes, together with human influences on the system, will govern the changes with time at any particular location of interest. Nevertheless, present-day site-specific information should be incorporated into the biosphere system description as far as possible, especially in relation to the characterisation of those features that may be less susceptible to modification as a result of climate change and human influence. Descriptions of present-day biosphere systems, with characteristics representative of climate and landscapes that may be of interest in the future, can also provide useful analogues for the future. The MICE project (Agüero et al., 1996) provides a methodology for the development of generic biosphere system descriptions following such an approach.

BIOMOVS II developed a systematic process (the 'Reference Biosphere Methodology') for establishing a logical audit trail to justify the scope, constituents and definition of assessment biospheres (BIOMOVS II, 1996). BIOMASS Theme 1 has been designed to develop the concept of the Reference Biosphere into a practical system for application to long-term safety assessment. This has involved application and augmentation of the Reference Biosphere Methodology, during which the BIOMASS Methodology has been developed.

The ways in which different elements of the process relate to each other are not easily expressed in a simplified illustration; nevertheless, an effort to demonstrate these relationships as a set of discrete actions and procedures is presented in Figure B1.

The BIOMASS Methodology provides the necessary logical framework for the development of biosphere system descriptions and models relevant to radiological impact assessment for the long term, and their justification. It involves the following activities:

— Defining the alternative **assessment contexts** within which the Reference Biosphere(s) is to be applied for a number of example cases (Section B2).

— **Identifying and justifying** biosphere systems relevant to long term assessment (Section B3).

— Developing practical **descriptions** of the identified biosphere systems, in sufficient detail to support model development (Section B4).

— Establishing and justifying the assumptions made regarding the behaviour of **potential exposure groups** (Section B5).

— Developing **models** for radiological assessment consistent with the assumed potential exposure groups and their environments (Section B6).

— Adopting a consistent and rational approach to the use of **data** required throughout the process (Sections B4, B5 and B6).

Each of these separate aspects is summarised below:

*Consideration of alternative assessment contexts*

The approach taken in long-term biosphere assessment needs to be consistent with the objectives of the overall performance assessment, the endpoints to be evaluated and the characteristics of the release from the geosphere. These issues are themselves influenced by national regulations, the stage of development of the repository programme and the major features of the disposal system together with its associated performance assessment.

*Biosphere system identification and justification*

A range of approaches can be taken in respect of the degree of abstraction adopted in representing the biosphere for performance assessments. The justification of choices made in identifying and defining stylised futures relevant to the evaluation of radiological impacts in the long term is a key step in the development of a coherent assessment approach.

Provisionally, the biosphere system is defined within the BIOMASS Methodology as a set of specific characteristics which describe the biotic and abiotic components of the surface (or near surface) environment and their relationships which are relevant to safety assessments of solid radioactive waste disposal. The biosphere system (and associated chemical, physical, and biological processes) forms the link between the geosphere system (and associated processes which affect radionuclide transport from the disposal facility) and the ultimate radiological impacts to be assessed. The boundary between the geosphere and biosphere systems will be context specific and must be consistently defined within the assessment. The principal components of the biosphere system are defined as: human activities; climate; topography; location; geographical extent; biota (fauna plus flora); near surface lithostratigraphy (geology plus soils & sediments); and water bodies.

*Biosphere system description*

Having identified biosphere systems relevant to long-term assessment, the next step is to provide practical and self-consistent stylised descriptions of such systems. This involves characterising the spatial domain, constituents and system dynamics, taking account of underlying assumptions regarding human behaviour as well as the overall assessment context.

As a general rule, such stylised descriptions of the biosphere will be conditioned by the overall objective of evaluating radiological impacts. Nevertheless, descriptions that form a basis for assessment modelling may properly be considered independently of any potential radionuclide input, thereby addressing broader concerns regarding assumptions that underlie the safety assessment. The validity of the system description must also be addressed; this will involve systematic consideration of potentially relevant features, events and processes (FEPs), as well as making informed and consistent choices regarding quantification of the system parameters. The necessity to ensure consistency within the biosphere description will usually require consideration of the main characteristics of the likely exposure groups, and the availability and nature of data.

*Principles for the definition of critical and other hypothetical exposure groups*

Assumptions regarding the behaviour of human communities are fundamental to the evaluation of radiological exposure as well as the definition of future biosphere systems. The effects of human communities on the system being described must be considered, as well as the impact of radionuclide transport through the system and the resulting exposure pathways. Issues such as self-consistency and conservatism in choice of data, as well as questions of homogeneity and averaging, with reference to a range of potential assessment contexts must be addressed. Consideration should also given to whether hypothetical critical groups can or should be defined a priori, or if they are more properly identified a posteriori on the basis of evaluating exposure to a range of candidate groups resulting from the assumed migration and accumulation of radionuclides in various biosphere media and the consequent variety of combinations of exposure pathways.

*Model development*

Model development can be considered in three main stages - definition of a conceptual model, a mathematical description and, finally, the assessment tool itself. The assessment context, biosphere system description and exposure group definition all need to be addressed in developing appropriate models for evaluating radionuclide transport and radiological exposure.

In BIOMASS Theme 1, work focused mainly on the development of conceptual model descriptions. In defining the model domain, specific consideration needs to be given to boundary processes, both in terms of the source term of radionuclides to the biosphere and potential losses from the system. Model components and their relationships are examined against the range of features, events and processes included in the BIOMOVS II international FEP-list (BIOMOVS II, 1996) as reorganised and extended in Annex BIV to this document.

*Principles for the application of data to assessment models*

The quantitative results of assessment calculations ultimately depend on the quality of the parameter data base that underlies the calculations and the authority of the assessment result will depend on the rigour in which data have been selected. Construction of data bases for biosphere modelling typically involves substantial interpretation and extrapolation, based on a broad range of sources of information.

Considerations include: the definition of 'effective' parameters for long-term modelling, taking account of the different temporal and spatial scales over which data are collected and applied; questions concerning data availability with respect to the characterisation of radioecological parameters for different environmental conditions; and approaches for addressing data uncertainty. The BIOMASS system for the development of Reference Biospheres includes a protocol for data selection.

# B2. ASSESSMENT CONTEXT

## B2.1. WHAT IS THE ASSESSMENT CONTEXT?

Development of an assessment context has been recognised as an important first step in the Reference Biosphere Methodology as set out in BIOMOVS II (1996a).

It is assumed that some form of assessment is being carried out of the post-closure performance of a solid radioactive waste repository. The assessment context answers fundamental questions about the performance assessment (PA), namely:

— what are you trying to assess? and
— why are you trying to assess it?
— In a quantitative assessment, these questions become:
— what are you trying to calculate? and
— why are you trying to calculate it?

Historically, the questions have not been answered very clearly.

For the near field modeller it was, nevertheless, quite simple. The answers to the two questions were: 1) radionuclide release from the near field, and 2) because the geosphere modeller needs this as input to far field modelling. For the far field modeller, things were equally simple. The answers were: 1) radionuclide release from the far field, and 2) because the biosphere modeller needs this as input to biosphere modelling.

For the biosphere modeller, the answers were not so simple. The scope of the biosphere models is, in general terms, migration and accumulation of radionuclides in the biosphere and the estimation of the radiological impacts on environmental and human health. However, concerning what is to be calculated, there was generally no agreement on what type of dose or risk to calculate. Dose to whom? Risk of what? Concerning why, sometimes the intention would be to demonstrate that a dose level would not be exceeded; in other cases the intention would be to assess the real dose. Without guidance, the biosphere assessors were left to make their own decisions. Sensible things were done in isolation, but the result could be inconsistent, both within individual total system performance assessments, and when different assessments were compared. This Section:

— identifies components of the assessment context relevant to the biosphere part of a PA;
— identifies alternatives for each context component, and discusses why and when each is relevant, and identify advantages and disadvantages associated with each alternative;
— considers the implications for biosphere model development, data requirements, etc.

The focus of BIOMASS Theme 1 was on issues concerned with the biosphere part of a repository PA and hence, upon the biosphere aspects of the assessment context. However, it is clear that the biosphere assessment context should be consistent with the context for the overall PA. It is assumed to be important that the overall PA assessment context and the context for each part of the PA (e.g. near field, far field and biosphere) should be coherent and consistent. For example, a consistent approach to treatment of uncertainties would be important since the major assessment conclusions would be dependent on evaluations made of all parts of the assessed system. This does not mean that exactly the same uncertainty analysis methods must be applied throughout, but that, for example, similar types of uncertainty should be treated similarly, and a consistent approach to pessimistic or realistic choices of parameters applied. The scale and rate of change in the biosphere results in the need for different treatment of uncertainties compared with other parts of the system.

Quality assurance is one increasingly emphasized requirement of PA, especially because of the need to trace decisions made within the assessment. However, this is taken to be more concerned with How? the PA is done than the What? and Why? referred to above.

The majority interest of BIOMASS Theme 1 participants was in long term release of radionuclides in groundwater at an inland site. This is reflected in the example assessment contexts considered. The discussion also illustrated that some important components of the assessment context arise directly from the overall PA, whereas others, such as assumptions about exposure group behaviour, could fall more specifically within the remit of the biosphere part of the PA. Overall, the ideas and concepts developed within BIOMASS should also be relevant to other types of release, such as gaseous and solid releases (the latter due to erosion or human intrusion), and releases at a coastal site into the marine environment.

## B2.2. IDENTIFICATION OF ASSESSMENT CONTEXT COMPONENTS

The requirements of a PA can have an important bearing on how the range of different potentially relevant biosphere FEPs are dealt with. In particular, the context of the assessment may play a key role in defining the model boundaries (both temporal and spatial), relevant assessment endpoints, and key assumptions concerning the biosphere system to be represented in the assessment.

The components of the assessment context are discussed below. However, many issues impact upon more than one component, and decisions in one area have influences in others. In real assessment situations, only some components of the assessment context may be provided to biosphere assessors, either by regulators or from the wider PA context. Other context components would remain to be specified by the biosphere assessors. In this case, it is very useful for the specification to be done at the start of the biosphere assessment, at least in a draft form as a basis for model development. As assessment work proceeds, it may be found appropriate to amend the initial assumptions in the light of consideration of factors such as data availability. It should also be recognised that it is possible for some issues which are, on the face of it, issues for biosphere model development to be pre-empted by external decisions. For example, regulations may specify the requirement to adopt specific assumptions about biosphere systems.

### B2.2.1. Purpose of the assessment

The general purpose of the biosphere part of a radioactive waste disposal assessment is to determine the radiological significance of potential future discharges of radionuclides. In any specific case, however, the purpose of conducting an assessment may vary from simple calculations to test initial ideas for disposal concepts, to support for a disposal licence application requiring detailed, site-specific performance assessment against regulatory criteria. The level of complexity and comprehensiveness will vary according to the use to which it will be put. Additionally, the assessment endpoints of interest may not only vary in type, depending on the assessment purpose, but also in the level of rigour required for compliance demonstration.

### B2.2.2. Endpoints of the assessment

The structure and composition of a biosphere model will tend to reflect the results that it is designed to evaluate. These, in turn, will largely depend on the criteria (regulatory or otherwise) that are adopted to judge the overall performance of the disposal system for a particular site, of which the biosphere is a part. Thus, for example, it may be appropriate that a model designed to assess the expected value of the effective dose to the average member of the critical group differs from another designed to evaluate endpoints, such as collective dose, concentrations of radionuclides in environmental media or the radiological impact on non-human biota. Several different endpoints may be necessary in development of the safety case for a licensing application. The importance of the selection of appropriate endpoints in the assessment process has been highlighted in a wider context by the US Environmental Protection Agency (1996).

### B2.2.3. Assessment philosophy

The reason for including this context component arises from the apparent different approaches that can be applied to the assessment of specific endpoints. While the nature of the endpoint may have been clearly defined, the nature of the assumptions used in assessment of the endpoint also need to be made clear. A particularly important example concerns the degree of pessimism to be introduced when defining assumptions for hypothetical critical groups (BIOMOVS II, 1996a). Many different assumptions have been made in previous assessments which have had important implications for the values of the assessed doses, even though the apparent initial intent in assessing the doses was to address the same endpoint. BIOMOVS II indicated that advice on this issue is generally lacking in regulatory guidance. Furthermore, sometimes the performance assessments have not been consistent with what advice there is. While critical group assumptions are an important example, it is clear that the problems with adopting a consistent approach to the level of pessimism can arise in any part of the assessment. As a contribution to solving these problems, a statement setting out the approach to be taken should be included in the assessment context.

### B2.2.4. Repository system

The description of the process system to be represented in a biosphere model must be consistent with the known details of the disposal facility being considered, including the type of repository under consideration. For example, the type of repository (characterised by depth, host rock, waste type etc.), in conjunction with other context components such as evolution of future climate (site context) or time frame, may support identification of other context components, such as radionuclides of concern, or geosphere/biosphere interface(s).

### B2.2.5. Site context

The general location of a repository may have an important influence on the likely pathways for release of radionuclides to the biosphere and the extent to which factors such as climate and ecological change can influence the impact of such releases. For example, a coastal location may provide a marine receptor for radionuclides released from the repository, whereas an assessment for an inland mountain location may not need to address marine FEPs. Additionally, site context should define, in general terms, the current surface topography and climate in the vicinity of the site. For example, the topography at some sites may suggest lacustrine environments whereas, in others, lakes are not common.

The information provided under site context could be a mixture of verifiable information associated with present day conditions together with a set of assumptions about the way that the site might evolve in future. In the complete absence of site-specific data, the site context will be wholly generic and will consist of a set of assumptions made for assessment purposes. It could also be a mixture of site-specific and generic information. In any case, a clear distinction should be made between the verifiable information and the assumptions made for assessment purposes.

The site context may help to define the spatial domain to be included within the biosphere system description. The domain may also be influenced by the exposure groups which have to be considered, in turn, potentially affected by societal assumptions, discussed below. For example, if only a narrowly defined critical group is to be considered, then a limited spatial domain may be sufficient. If, however, an indicator of collective radiological impact is required, as in guidance provided by the UK authorising departments (Environment Agency et al., 1997) a wider domain may need to be considered, depending on the nature of the exposure group. Endpoints are therefore also important. This shows how the different components of assessment context can interact.

#### B2.2.6. Source terms and geosphere-biosphere interface

The structure and modelling requirements of the biosphere model will be dependent on the radionuclides under consideration and the interfaces assumed between the geosphere and biosphere. It is important that all relevant processes are included, either in the geosphere or biosphere models and, in general terms, this requires a clear definition of the interface as well as clear recognition of where in the assessment particular processes are being taken account of.

Model requirements for some radionuclides will be very different from others. For example, the environmental behaviour of plutonium isotopes is very different from that of Cl-36. The specific interface(s) between the geosphere and biosphere, which could be gaseous, aquatic, terrestrial, or an intruding well, or yet other alternatives, will be determined as part of interactions between the biosphere modeller(s) and geosphere/engineered systems modeller(s). Additionally, the geosphere-biosphere interface(s) may be time-dependent because of site evolution, as modelled in the geosphere and/or biosphere parts of the PA. Decisions about which radionuclides and interfaces to include can be based, in part, on previous analyses or ancillary modelling.

#### B2.2.7. Time frames

Waste disposal should ensure equitable protection of both current and future generations; this will involve balancing greater certainty for shorter time periods with increasing uncertainty over longer time periods. An appropriate time frame should also provide information to the decision maker on potential impacts from short- and long-term hazards and should facilitate distinction between alternative disposal sites. The time frame should be selected, recognising inherent limitations and uncertainties in assessment methodologies, as well as constraints on the scientific credibility of long-term estimates of repository performance imposed by unpredictable, large scale geologic changes. The selection of a specific time frame can have considerable impact on considerations in biosphere modelling such as relative importance of site evolution, critical radionuclides, and geosphere/biosphere interfaces.

#### B2.2.8. Societal assumptions

As there is little technical basis for predicting the nature or probability of future human activities, it is necessary to make assumptions about future human habits in order to calculate future doses and risks. As part of development of the biosphere model, assumptions concerning future human actions will need to be defined, such as level of technological development, type of society (e.g. agricultural or urban), and basis for habits and characteristics (e.g. present day local behaviour or other sources for assumed behaviour). Societal assumptions are dependent on the degree of conservatism or realism desired in the analysis and the endpoints to be considered. Identification of the exposure groups under consideration as part of the biosphere modelling should be based, in part, on the societal assumptions and if the exposure groups have been previously identified and defined, the societal assumptions should not be inconsistent with that definition.

### B2.3. ALTERNATIVES FOR EACH CONTEXT COMPONENT

A number of different purposes can be envisaged for a PA which may have implications for Reference Biospheres and biosphere modelling. However, it can be presumed that the fundamental principles of radioactive waste management will have overall relevance or application to those different purposes. The IAEA provides just such a set of principles (IAEA, 1995) with the express purpose of giving a common basis for the development of more detailed standards and a basis for national waste management programmes. It is unnecessary to reproduce all the principles here and the associated discussion. However, the following four principles are reproduced here because of their particular relevance to post-closure PA.

- Principle 1: Protection of Human Health. Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
- Principle 2: Protection of the Environment. Radioactive waste shall be managed in such a way as to secure an acceptable level of protection of the environment.
- Principle 4: Protection of Future Generations. Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than the relevant levels of impact that are acceptable today.
- Principle 5: Burdens on Future Generations. Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

Text expanding on the meaning of these principles is provided in IAEA (1995). However, specific standards related to these principles and how to demonstrate compliance with them are, as the document itself says, the subject of further documentation. It is not the function of the present document to pre-empt such standards development. Rather, the intention is to take account of these principles in the consideration of the purpose of PA, and hence, to examine the implications for modelling activities.

#### B2.3.1. Alternative assessment purposes

**Demonstrate compliance with regulatory requirements/regulatory development:** In this case, the focus is to address the specific regulations and the related guidance from regulators. If regulations do not exist then the same type of assessment work could be used to support development of regulations. Although there is common reliance on international guidance, the regulatory interpretation varies in terms of the details. Some regulations are prescriptive in their form, giving relatively precise requirements and definitions, whereas others are more qualitative or may yet remain to be decided. In the latter case, the PA objectives may include provision of broader supporting analyses of safety issues and development of regulatory guidance, or even development of the regulations themselves. The detailed requirements may also vary according to the stage of repository development e.g. proof of concept, permission to construct, operating licence. The particular endpoints for which a standard has been set may have been defined. In general, the PA would therefore expect to address these endpoints. They may be quantitative or qualitative. Concerning quantitative endpoints, there is a big difference between having to show that the endpoint limits are not exceeded and having to assess the value of the endpoints themselves. The assessment specific requirement in this area should be made very clear.

**Contribute to public confidence:** In this case, there may be an increased focus on presentation of the types of results which can be readily absorbed by a less technical audience. It may also be necessary to address the interests of, say, local people with particular behaviour patterns, who wish to see the implications of those behaviour patterns addressed, whether they are critical or not. The key issue is that public interests may be wider than those of regulators. It is therefore important to recognise which additional factors should be addressed to meet that interest at the outset of the PA, not half way through the programme.

**Contribute to confidence of policy makers and the scientific community:** The assessment must satisfy these groups and other important opinion formers. However, they may have specific and different interests from those of the public generally. More detailed modelling might be required to address concerns here, beyond the detail required in a Total Systems Performance Assessment (TSPA) model. Sometimes this is called research modelling or auxiliary modelling, supporting the PA modelling assumptions. The results may be used to justify simplifications adopted in a TSPA model. Policy makers may also be interested in a simple measuring stick, using radiological protection terms, which can be used to roughly assess the performance of a proposed disposal system. The measuring stick may be used to compare different disposal systems or to gauge the absolute adequacy of a particular proposal.

**Guide research priorities:** Intermediate endpoints may be of interest here and not just the final regulatory endpoints. The objective could be to compare investigation needs in the near field and/or the geosphere relative to the biosphere, or the focus could be on identifying the research priorities within the biosphere part of the PA. In either case, radionuclide specific priorities could be of interest.

**Proof of concept:** A lower level of detail may be acceptable in this case compared to that required in the latter stages of repository development. If no specific sites are identified, then no site specific data can be used. However, it may be convenient to consider a range of site type alternatives, such as inland and coastal.

**Guide to site selection and approval at later stages in repository development:** Fuller information should become available in later stages of repository development. This should include details of the site itself but also results of preliminary PAs. The latter should include the more likely important mechanisms for release of radionuclides into the biosphere, as well as which radionuclides are involved. Such information may significantly reduce the level of effort required for detailed modelling, providing important focus for the biosphere part of the PA.

**System optimisation:** In radiation protection terms, optimisation generally requires that in relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where they are not certain to occur, should be kept as low as reasonably achievable, economic and social factors being taken into account (the ALARA principle). However, it is not obvious how biosphere modelling results relating to the very long term could contribute significantly to that process. Unlike, for example, engineered barriers, the biosphere cannot be modified to provide greater safety. Treatment of optimisation may be dependent upon regulatory requirements and guidance on the application of the ALARA principle to long term post-closure situations.

### B2.3.2. Alternative assessment endpoints

These need to correspond with the assessment purpose, for example, the quantities for which limits or constraints have been set to demonstrate compliance with regulatory criteria. In this case each regulatory endpoint needs to be adequately defined. A previously recognised problem is that hypothetical critical groups have not been easy to define in the quantitative terms required for a quantitative assessment. Similarly, risk is not easy to define, or there have been different definitions. So far as possible, such definitions should be defined in advance of the detailed PA work. At the same time, it can be recognised that it may be part of the purpose of the PA to develop improved definitions.

Each endpoint may be considered differently within different time frames (IAEA, 1994).

An additional consideration is that the trend in safety case development is not to rely on evaluation of just a single issue, such as individual risk. Multiple lines of reasoning may be useful. Regulators and others may use a wide range of arguments and endpoints to help determine the adequacy of a safety case. A variety of indicators may be used as alternatives to dose and risk. The complete set of indicators may correspond to the complete set of potential endpoints e.g. estimates of radionuclide concentrations in the environment may be both regulatory endpoints as well as providing guidance for future priorities in data collection and research.

Even if an assessment is done for a stated particular purpose e.g. regulatory compliance, the assessment can still be criticised for not having a wider scope, for example as regulatory requirements change; thus in any assessment, it may be useful to consider all potentially relevant purposes. So far as the modelling is concerned, this means considering all the potentially relevant endpoints.

The following alternatives have been identified as potentially relevant:

**Individual risk:** Risk of some form of health detriment due to radiation exposure has the advantage that it can be compared with risks of similar health detriments due to other causes. The risks can be explained without the need to explain the complications of radiation protection quantities. The risk quantity allows for inclusion of high-consequence/low-probability events, and probabilistic risk assessment provides a quantitative formalism for incorporating the effects of parameter uncertainty.

However, risk remains a difficult quantity to define and a difficult quantity to explain. Mathematical expressions for risk do not generally coincide with public perception of what risk is. Combining the range of possible events which might occur before some point in the future when radionuclide release might occur and including them coherently in a model may be extremely difficult. The location of the exposed group in time and space can be combined in a number of ways with the operation of averaging over parameter distributions to give a number of different but internally consistent risk definitions. A clear expression is required of what type of risks are to be considered, and to whom.

**Individual dose:** Individual dose has the complementary disadvantages and advantages of risk.

For both or either of individual dose and risk it may be of interest to assess not only values representative of the most highly exposed but also the more likely levels of exposure. It is also possible to consider the individual dose distribution among different populations living in the vicinity of the site and in the region beyond that. Given the long timescales involved, any assumptions about such populations would be speculative. Clearly, those responsible for choosing model parameter values need to know what is required in this respect. It is appropriate to develop a consistent approach to choosing parameter values or extremes of parameter ranges as regards the degree of pessimism. As regards parameters directly affecting exposure, descriptions of the nature of the exposure or the exposed group will provide guidance. However, it is not always clear whether this should be part of the assessment context, or part of the assessment itself.

Again, for both or either of individual dose and risk, it is necessary to be explicit about what types of dose (effective or other) the model is to calculate, and for whom e.g. adult, child, others.

Any assumptions about the exposed groups could have implications for the detailed descriptions of the biosphere systems which have to be modelled.

**Collective doses and risks:** Collective dose is the total dose received by an exposed population. It can be argued that assumptions about population exposures are very uncertain. SSI (1997) includes the requirement to consider collective doses integrated over a limited period but suggests that collective dose estimates should be viewed only as an aid to comparison of options. To aid such comparisons, it may be appropriate to present collective dose estimates broken down over separate periods of time and spatial domains, with an indication of the individual dose rate at which the collective dose is delivered (ICRP, 1998).

**Doses to non-human biota:** One of the key principles referred to in Section B2.3 is Protection of the Environment (IAEA, 1995). The IAEA has a set up a group to develop protection guidelines for the environment which includes consideration of the appropriate corresponding assessment endpoints.

**Modifications to the radiation environment: distribution/concentration of repository radionuclides in the environment:** A range of alternatives to dose and risk can be used as repository safety indicators (IAEA, 1994). They include a variety of comparisons with natural background, such as radiation dose rates in different locations, radionuclide concentrations in different media such as soils and sediments, but also in foodstuffs and breathable air. The estimates of these quantities are less dependent on seemingly arbitrary assumptions about human behaviour, but are also less indicative of the impact on human health. There is still a need to assess the migration and accumulation of radionuclides through the biosphere. The comparisons may need to be carefully considered e.g. because the repository and natural radionuclides are not all the same. A variety of evidence can be used to enhance or improve the relevance of the comparisons, taking account of data on relative radiotoxicity and environmental mobility of the radionuclides concerned.

In general terms, the requirements for data on radionuclide migration and accumulation will be no more onerous than those for the dose and risk related endpoints.

**Fluxes into or through parts of the biosphere:** These are even less dependent on arbitrary assumptions about human behaviour, but are even less indicative of the real impact.

For fluxes into the biosphere, there is no need to assess the migration and accumulation of radionuclides through the biosphere. However, there is still a need to clearly define the end of the far field geosphere model and to consider the interactions between geosphere and biosphere systems. It is important to structure the organisation of the PA to allow this to be done sensibly.

For fluxes through parts of the biosphere e.g. from land to surface waters, the modelling requirements are similar to those considered in respect of comparisons with the natural radiation environment.

**Estimates of uncertainties or confidence:** In one sense, an estimate of uncertainty or confidence can be regarded as just one aspect of each endpoint rather than an endpoint in itself. However, the importance of this issue warrants separate consideration. There may be specific regulatory requirements regarding levels of confidence attached to the calculated quantity e.g. dose, as well as the likelihood that the circumstances giving rise to the dose will arise. There are links between risk definition and uncertainties, as noted above.

There are many ways of estimating uncertainties and expressing levels of confidence (see BIOMOVS II (1996b) for example references relevant to biosphere modelling). The assessment context should include guidance on how to deal with conceptual uncertainties as well as parameter uncertainties as part of the assessment philosophy. Such guidance should be consistent across the whole PA.

### B2.3.3. Alternative assessment philosophies

A range of approaches can be considered and two are presented here, representative of approaches that have been used before and based on work in BIOMOVS II (1996a). The first is termed "cautious", the second is termed "equitable". They should not be considered as opposites. That is, a cautious approach should not be considered as inequitable; equally, an equitable approach should not be considered as reckless. Rather, they represent two illustrations along a philosophical continuum.

The assumption behind the cautious philosophy is that safety is provided by ensuring that nobody will ever receive anything more than a very small dose (or health risk) from radioactive waste disposal. This implies that assumptions relevant to individual dose assessment should be pessimistic and would focus on those very few people who would receive the very highest doses, as with members of critical groups identified in the assessment of present day releases.

The assumption behind the equitable philosophy is that radioactive waste disposal constitutes a health risk to present and future generations like many other risks that society chooses to tolerate. To be equitable, it should be regulated to the same level as these other risks. Some of the levels of risks that society currently tolerates and that regulators use in setting standards are based on society wide averages rather than on specific higher risk subgroups. In contrast with the cautious approach, the equitable assessment philosophy implies defining exposure groups on a wider, less pessimistic, basis.

Although the distinction between cautious and equitable is not always clear, it is important to apply an assessment approach consistent with the approach adopted in setting the criteria. Thus, it is important for policy makers to provide as much description of the assessment philosophy as possible so that consistency with that philosophy can be maintained between regulations and approaches to evaluating compliance.

### B2.3.4. Alternative repository systems

This context component can be subdivided into three categories of information: depth of repository, host geological medium, and waste type.

The use of long term monitored storage, in a variety of forms, has been a major issue in public discussions and formal hearings. Based on legal requirements, these types of other solutions have been considered as alternative solutions in environmental impact assessments carried out or under way for HLW disposal projects in several countries. Consequently, it is appropriate to carry out assessments of these alternatives and to undertake comparative assessments of the alternatives. In the case of options based on long-term monitoring and retrieval of wastes emplaced in a deep repository, the releases to the accessible environment and subsequent transport in the biosphere are not expected to be very much different from the situation related to an already sealed repository. On the other hand, monitored storage is not disposal. Furthermore, it is quite generally considered (NEA, 1995) that, from the ethical point of view, it is better to rely on geological disposal as compared to the option of prolonged surface storage since the latter option transfers the responsibilities associated with the waste management to future generations. Although disposal impacts may be compared with storage impacts in determining appropriate waste management options, storage assessment was beyond the scope of BIOMASS Theme 1.

**Depth of repository and host geological medium:** The depth of the repository and host geological medium can be important inputs to the selection of time frames and geosphere-biosphere interfaces. Both of these context components are usually provided to the assessor and are not matters of choice. For proof of concept analyses, and other scoping analyses, the information provided may be vague, but the assumptions made should be stated.

**Waste type:** The waste type will have a strong influence on the key radionuclide(s) considered in the biosphere part of the PA. General waste types include low-level radioactive waste, intermediate-level radioactive waste, vitrified high-level radioactive waste, spent fuel, and transuranic wastes. Deep geological disposal is expected to be used for any wastes containing a significant proportion of long-lived radionuclides.

The alternative of main interest to the BIOMASS Theme 1 participants was deep geological disposal, in several different host media. However, there was also interest in shallow disposal as well as in many different waste types, some of which would be potentially suitable for shallow disposal. The IAEA has initiated a coordinated research programme (ISAM) specifically devoted to the safety assessment of shallow repositories (IAEA, 1997).

### B2.3.5. Alternative site contexts

The site context describes the physical features of the current biosphere around the repository and should especially focus on areas encompassing the geosphere-biosphere interfaces. The site context should include brief descriptions of the current local site conditions, such as surface topography (e.g. mountainous, hilly, flat, location of valleys etc.), current climate, surface lithology and soil types (focused on suitability for farming practices), fauna and flora, local surface water bodies ( e.g. rivers, artesian wells, ponds, wetlands etc.), and near-surface aquifers. If such information is not made available to the biosphere assessment team as part of the assessment context, then appropriate choices must be developed within the assessment, initially in identifying and justifying biosphere systems. The spatial extent of the site context description depends on the type of endpoint(s) employed in a particular assessment. For individual dose and risk, the significance of variability in local conditions is much larger, whereas in the case of collective impact indicators, especially global collective dose, the level of impacts is less sensitive to local conditions.

The biosphere modeller(s) can use the information given in the site context, along with information from other context components to identify receptors of interest. For example, because of local conditions, such as deep water sources, lack of good soil types, and mountainous surface topography, the closest receptor for the individual dose endpoint is limited to using a deep well and using the abstracted water for drinking and household uses only.

The site context will help to define the spatial domain to be included within the biosphere system description. The variability of sites is so large that it is unlikely that a single site context could reasonably cover all relevant variations. This suggests that one Reference Biosphere could not adequately be applied to a variety of sites unless only limited objectives were being set, as discussed above. Even at a single site, environmental changes within the time frame of interest could take many forms. The assessment context should at least provide guidance as to whether the potential for such change needs to be considered in the assessment. Site climate and its evolution as well as type of landscape (flat or mountainous) and surface topography (type of overburden, bedrock outcrop, wetland), could all be relevant and thus deserve inclusion as alternatives for site context. However, a clear distinction should be retained between verifiable information and assumptions made for assessment purposes.

### B2.3.6. Alternative source terms and geosphere-biosphere interface

Alternatives considered in BIOMASS Theme 1 relate only to groundwater release from the geosphere at an inland site. Even so, many different interfaces can be envisaged. According to Davis et al., (1993), who considered disposal on the Canadian shield, contaminated groundwater could reach the surface and enter the biosphere at three distinct types of discharge zones. In the case that the repository is located close to a surface water body (for example a lake or river), the discharge would occur primarily to the water body itself through deeper and upper sediment layers. Depending on the type of landscape, part of the discharge could be directed to a soil zone underlying a terrestrial area that could be exploited by agricultural activities or be suitable for natural or semi-natural biota. This terrestrial area could be subject to future temporal evolutions between alternative formations (lake or river bottom, wetland and farming or agricultural area). The third distinct type of discharge point identified was a bedrock well drilled into the contaminated groundwater plume.

More generally, many different types of near surface aquifer can be envisaged, discharging directly into the biosphere or from which water is abstracted via a well. In many performance assessment studies e.g. Nirex (1995a) and Nagra (1988; 1994a,b), the geosphere and biosphere analyses are decoupled from each other. In simplified approaches the flux of radionuclides entrained in the groundwater flow system is analysed by geosphere models and this flux is assumed to discharge directly into a biopshere receptor, without detailed consideration of the transport mechanisms involved. In more detailed analyses, which require a more comprehensive data base, specific models have been developed and applied, such as the SHETRAN model (Nirex, 1995b) and that of Davis et al., (1993). These explicitly take account of processes and radionuclide transfer at the geosphere-biosphere interface.

The detailed configuration and characteristics of the interface between the biosphere and geosphere is site specific and may be time-dependent because of site evolution due to, for example, climate change and human activities. For example, in the case of discharge to a surface water body, there may be transport through bed sediments and deeper sediments to consider. Radionuclide concentrations in and transport through sediments could be important because of the implications for rate of release into the surface waters, but also because sediments may later be converted into a substrate on which crops and other plants can grow. Corresponding changes could arise in the case of discharges entering soil from below. For discharge via a well, abstraction effects on the groundwater flow system and other possible effects on radionuclide migration might need to be considered, potentially involving feedback assumptions for the geosphere modelling.

### B2.3.7. Time frame

Describing the environmental conditions for humans in the future becomes more and more speculative as the time frame considered within the assessment gets longer. Furthermore, different endpoints may have different significance within different time frames, as suggested in IAEA (1994). Therefore, it is necessary to discuss time frames when developing biosphere models and when interpreting the model results.

Time-related factors include:

- institutional control period;
- natural and human induced surface environment changes;
- engineered barrier system degradation;
- geological environment changes;
- time before commencement and then temporal extent of the assessed releases from the geosphere; and
- half-lives of relevant radionuclides.

Some examples of views expressed in previous studies are given below to illustrate the alternatives and highlight the implications. It is clear that, whichever view is taken, the requirements for biosphere modelling will vary. For example, the level of detail required after $10^4$ years may be much reduced.

**From closure to 100 years:** Since it is expected that institutional control remains in place for a period of around 100 years after repository closure, any inadvertent human intrusion into the repository should be precluded during this period. In addition, significant changes to the surface environment are not expected to occur over this time period. It has therefore been suggested that present day conditions can be assumed for the biosphere system within this period. Concerning half-lives, it is clear that some short-lived radionuclides would decay significantly during this period.

**From 100 to $10^4$ years:** Although it is expected that some form of passive institutional control e.g. keeping of records and setting planning conditions on site use, could be active over this period (Jensen, 1993; Eng et al., 1996), institutional control is generally assumed not be reliable for such long times. Concerning the surface environment, it can be argued that some major features of the biosphere will probably remain comparable to present day conditions although human behaviour may change significantly and major changes in climate could occur. Regarding the radionuclides, many short-lived radionuclides will decay over this period, and the radio-toxicity of many waste types will fall substantially.

**From $10^4$ to $10^6$ years:** The next glaciation period is expected to occur around $10^4$ to $10^5$ years from now. It is expected that the considerable climate change involved will have a significant influence on the disposal system as a whole and the near-surface environment in particular. The range of possible biosphere conditions and human behaviour is too great to allow reliable predictions. The treatment and assumptions associated with exposure groups might therefore be different (IAEA, 1999). However, the deep geological environment may be considered to remain stable beyond the next period of glaciation. Regarding the waste, the hazard associated with remaining radionuclides in this time frame falls to a level similar to or lower than the natural uranium ore from which reactor fuel is made (IAEA, 1994). Some regulations specifically limit the level of detailed consideration of radiological impact due to releases occurring after $10^4$ years, (e.g. US Environmental Protection Agency, 1985; AECB, 1987; Bosser, 1993). By contrast, some (e.g. HSK and KSA, 1993; NAS, 1995; AEC, 1997) have suggested calculating impacts out to the peak of release. Engineered barrier and groundwater flow systems may be changing significantly within this time frame and the assumptions used in modelling those changes should be consistent with assumptions used in the biosphere.

**Beyond $10^6$ years:** It is suggested that any assumptions on time-related factors except the source term have little relevance in this timeframe. Geological factors may be relevant on such time frames.

### B2.3.8. Societal assumptions

Assumptions related to future human behaviour and habits are key issues in defining Reference Biospheres. One commonly accepted approach is to use current data. If changes at the site have to be taken into account, current data from other sites which presently reflect the assumed changed conditions can be used. This is on the basis that the variability in present conditions at different locations is one way of representing the spectrum of the future variability at any particular single site.

The spatial extent of the domain may also be influenced by the exposure groups which have to be considered. In the case that only a narrowly defined critical group is to be considered, then a narrow domain may be sufficient. For example, if it is considered sufficient to assess individual doses due to consumption of drinking water derived from a well at some location defined by geosphere modelling, the amount of data needed is quite restricted. However, consideration of a wider range of exposure groups will result in greater data requirements. If an assessment is required of an indicator of collective radiological impact, as suggested in guidance provided by the UK authorising departments (Environment Agency et al., 1997), then a wider domain may need to be considered, depending on the definition of that collective indicator. If the spatial domain is restricted, the results are much more sensitive to variability and temporal evolution of local conditions as compared to indicators describing the impacts on much larger domains (regional or global). For the latter type of applications, the impacts may be more directly dependent on the total amounts of release and it may be sufficient to rely on simple conversion factors between the impact indicator and total release.

One way of expressing societal assumptions is to consider the level of exploitation of the local resources. Possible alternatives to consider include: intensive or extensive farming and use of modern technology or assuming simple technology associated with subsistence farming (SKI, 1989). It is not usually considered appropriate to make assumptions about improved technology, such as new cures for cancer or major new advances in detection and mitigation of radiation effects.

### B2.4. IMPLICATIONS FOR MODEL DEVELOPMENT

The documentation of the assessment context should state as clearly as possible the requirements of the biosphere modeller. The defined context components not only state the purpose, endpoints and key readily identifiable facts of the system (repository type, site context); they also identify basic premises for the treatment of uncertainty and the less predictable aspects of biosphere evolution, such as the geosphere-biosphere interface. For example, by documenting basic premises about the geosphere/biosphere interface, problems with understanding the degree of linkage with the rest of the PA are reduced. Clear identification of the context components such as site context, key radionuclides, societal assumptions, and endpoints may be used to limit the scope of the biosphere modelling. The assessment context can also give an indication of the degree of complexity the biosphere modelling may be required to contain. As an illustration, if the assessment context requires:

— assessment of multiple endpoints (individual dose, collective risk, and dose to non-human biota);
— using present day human behaviour patterns potentially applicable at the site in question;
— inclusion of the near-surface aquifer;
— site evolution for a period of 1 million years; and
— possible releases encompassing over 75 radionuclides;

the resulting biosphere model could be quite complex.

It follows that, if the objective is to provide a widely applicable international measuring tool, then it is likely that the level of biosphere model details will be low, since any details would tend to rely on specific information which could not be generically relevant. Conversely, if many issues are to be addressed, the model will be complicated and have high data requirements, and it will be less generally applicable.

Most of the information related to repository systems will indirectly affect the biosphere modelling as it more directly affects the selection of other context components, such as supporting the decision on the radionuclide(s) modelled, geosphere-biosphere interface(s), and time frames to be considered.

The biosphere modeller(s) can use the information in the site context, along with other assessment context information, to identify the biosphere receptors of interest. For example, because of local conditions, such as availability of deep water sources, lack of good soil types, and mountainous surface topography, the closest receptor for the individual dose endpoint could be limited to a deep well and use of abstracted water for drinking and household uses only. Additionally, the site context could be used to guide whether new endpoints are necessary. For example, if the repository is at a coastal location, the assessment might need to include benthic biota as an endpoint, especially if one of the main geosphere-biosphere interfaces is release to marine sediments.

It has been suggested that there can be value in trying to simultaneously address more than one assessment purpose or objective. This is legitimate of course, but could then lead to separate requirements from models. Multiple purposes may require multi-functional models. In practice, the long-timescale for the development and operation of a radioactive waste repository, several decades or more, means that regulations and other requirements may change significantly during the repository development programme. So far as possible, it is helpful to anticipate changes, but at the same time, relevant focus must be retained within the current phase of work. Careful development of an assessment context should help develop the appropriate compromise.

If all components of the assessment context are not provided or addressed by those who commission the assessment, then they should be addressed by those responsible for carrying out the assessment. Apart from providing the set of premises for developing the assessment or Reference Biospheres, the assessment context will help to establish the appropriate level of documentation required to produce the necessary traceability and transparency of the assessment.

## B3. IDENTIFICATION AND JUSTIFICATION OF BIOSPHERE SYSTEM(S)

### B3.1. IDENTIFICATION AND JUSTIFICATION PROCEDURE

The approach to biosphere system identification and justification is presented as a decision tree in Figure B2.

In summary, the overall approach consists of up to three steps. In Step 1, the assessment context is reviewed to establish whether or not it pre-defines the biosphere system(s) that are to be considered. If it does not, the components of the biosphere system(s) to be represented are identified and justified according to an interpretation of the assessment requirements, taking account of the site context. In Step 2, with further guidance from the assessment context, a decision is taken as to whether or not biosphere system change is to be considered. If biosphere change needs to be addressed, the mechanisms responsible for change are identified and their associated potential impacts on the biosphere system described. These changes are then linked together as one or more narratives of the anticipated possible future evolution of the biosphere system. Finally, in Step 3, an approach is selected for representing the implications of biosphere system change within the assessment.

#### B3.1.1. Step 1: Review the assessment context

When attempting to identify and justify the biosphere system to be considered, the first step is to review the information provided by the assessment context that is pertinent to the case. There are basically two main situations, as shown in Figure B2 and described in the following sub-sections.

*B3.1.1.1. Biosphere system pre-defined by explicit legislation or guidance*

At one extreme, the assessment context might state that the biosphere system to be assessed is pre-defined by explicit legislation/guidance, or by those commissioning the assessment. For example, it might be stated that the assessment biosphere system should represent the current biosphere system at the disposal site. The system can then be described (see Section B4) from the predefined system.

> ***See Box 1 of Figure B2:*** *The biosphere system to be described is pre-defined by explicit legislation/guidance.*

This was the case (for example) in the 1998 assessment of proposed high-level radioactive waste (HLW) disposal at Yucca Mountain undertaken by the United States Department of Energy (USDOE) (Tappen, 1997).

*B3.1.1.2. Biosphere system not pre-defined by explicit legislation or guidance*

More commonly, the assessment context only constrains the system to be considered. For example, current French regulations require consideration of typical biospheres representative of the different climate states which might occur in the future at a disposal site, but the biosphere systems to be assessed are not pre-defined. In such cases, it is necessary to consider all potentially relevant components of the assessment context (Section B2).

Such information should provide a starting point for identifying and justifying the biosphere system to be considered for the given assessment context. Through a review of the assessment context, it should be possible to identify some initial information concerning the biosphere systems that need to be considered in the assessment. To allow for a clear identification and further description, the biosphere system is defined through a set of components that will be referred to as “principal components” of the biosphere system.

It is also relevant to note that the underlying assessment context can provide justification for developing a biosphere system description in which a substantial part, or even the whole, of one or more biosphere system principal components is essentially unimportant, or only of secondary importance, to the assessment.

The identification and justification stage then identifies which principal components are of primary interest and the selection of the principal component types from a list of categories proposed and given in the Series II Tables of Annex BI.

These principal components are listed below:

— **Climate and atmosphere** (see Table CI of Annex BI): Climate is the expression of meteorological parameters such as temperature, precipitation, evaporation, wind speed and direction over an area. These parameters should be described so that they are consistent with the other principal components of the biosphere system and/or on the basis of the assessment context. At a minimum, information should be provided concerning the broad classification of the assumed climate state(s) e.g. temperate, boreal etc. Climate will often have a profound effect on many of the other biosphere system principal components. Atmosphere is defined in terms of the composition of the air.

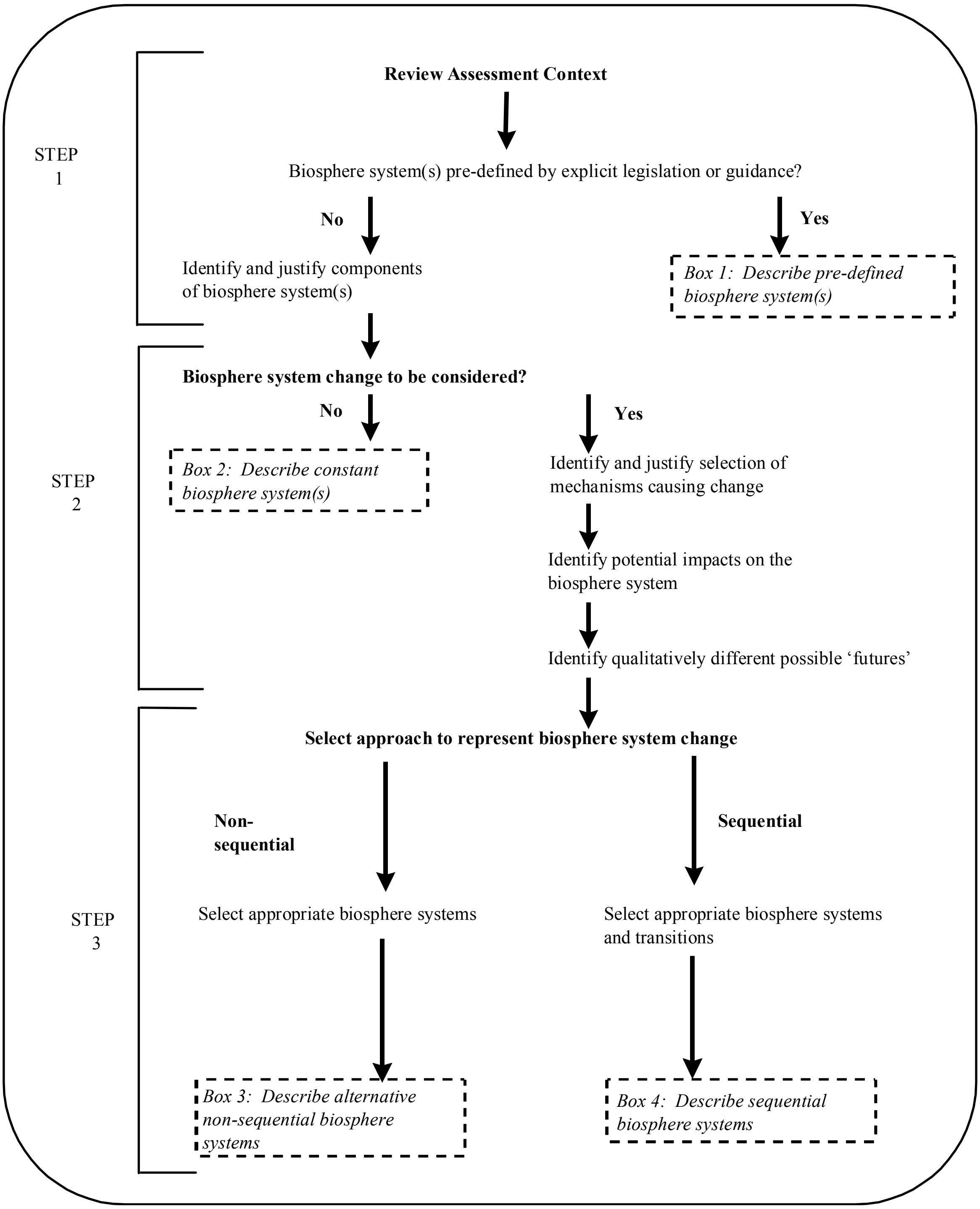


*FIG. B2. Decision tree for identification and justification of biosphere systems.*

— **Geographical extent** defines the boundaries/spatial domain of biosphere that is to be described. At a minimum, the area over which direct contamination of the biosphere may occur should be considered. It should be recognised that the extent might change as a function of time. Additional issues to consider when defining the geographical extent include: the end-point(s) of interest; human activities, especially resource area requirements; and the nature of the geosphere-biosphere interface.

— **Location** is the position of the biosphere system on the earth's surface. Information concerning latitude and longitude should be provided for site-specific contexts. For more generic situations less specific information might be available and might be restricted to more general information, for example whether the system is coastal or inland, and information describing its distance from the sea and altitude.

— **Topography** is the configuration of the earth's surface including its relief and relative positions of natural and man-made features (see Table TI of Annex BI). Information should be provided concerning the features of the system under consideration and its relief.

— **Human community** describes the nature of communities (e.g. agrarian vs industrial) (see Table HI of Annex BI); their habits; their level of technological development; and their degree of subsistence. This principal component of the biosphere system provides an indication of how humans utilise/exploit the environment/resources and the extent to which humans have disturbed or continue to disturb their environment.

— **Near-surface lithostratigraphy** describes the general characteristics of soils and sediments including both their composition and structure (see Tables GI and SI of Annex BI). It includes all weathered material above the bedrock and associated life forms (excluding those predefined under biota). It can include bedrocks if they contain aquifers which are considered to be within the biosphere.

— **Water bodies** are the surface and subsurface water masses e.g. lakes, rivers, wetlands, seas, and estuaries (see Table WI of Annex BI). These may include near-surface aquifers and ice-sheets. At a minimum, information should be provided as to whether such features are present in the biosphere system.

— **Biota** are the terrestrial and aquatic plant and animal life in the biosphere system (see Table BI of Annex BI). A distinction should be made between domestic and wild flora and fauna, and between those flora and fauna that are in the human food chain and those which are not but which are used by humans for purposes other than food.

Geographical context and location are outside the general summary classification presented in Annex BI. However, their implications are propagated through the whole system identification and justification process. For example, if the assessment end-points (one of the elements of the assessment context) include collective dose to the world population, then the biosphere system will be global in scale. If, however, the sole end-point is individual dose to members of a hypothetical exposure group living in the vicinity of the discharge from the repository, then the biosphere system might be restricted to the area around the discharge location. More detailed examples of how the assessment context can be used to identify principal components of the biosphere system to be considered are provided in the examples developed for a range of different assessment contexts (see Part C).

As noted in Section B2, the information provided by the assessment context, especially relating to the site context, could include verifiable information associated with present-day conditions at the site. Alternatively, it could relate to assumptions to be made for assessment purposes (for example, the assessment might be generic with little or no site-specific context, or it may be a requirement to make particular assumptions about site evolution). Often, the context will include a mixture of verifiable information and assumptions made for assessment purposes. Verifiable information may vary in quantity and quality, and assumptions may be of different degrees of specificity. Therefore, depending upon the nature of the assessment context, a range of biosphere systems might need to be identified and justified to a lesser or greater extent. These might relate to present biosphere conditions at the disposal site or they might relate to assumed future conditions.

In order to assist with the process of biosphere system identification, it has been found helpful to use a set of classification schemes (see Annex BI) that relate to certain basic categories for each of the biosphere system principal components. Such classification schemes also provide the necessary primary information to guide development of the biosphere system description to the level of detail required for modelling purposes. A summary that relates each of the principal components of the biosphere system, identified above, to the classification tables and characteristics used for the detailed biosphere system description (Section B4) is given in Table B1.

TABLE B1. ORGANISATION SCHEME RELATING PRINCIPAL COMPONENTS OF THE BIOSPHERE SYSTEM AND CORRESPONDING SCIENTIFIC AREAS TO TABLES LISTING CLASSIFICATION SCHEMES AND CHARACTERISTICS (SEE ANNEX BI)

| Biosphere system components | | | Characteristics (System Description) | |
|---|---|---|---|---|
| Principal components (*Related Scientific Areas* ) | Classification/Principal component types (System Identification) | | | |
| CLIMATE (*Climatology / Meteorology*) | Climate Classification | Table CI | Climate Characteristics | Table CII |
| WATER BODIES (*Hydrology / Hydrogeology / Hydrochemistry*) | Water Body Types | Table WI | Water Body Characteristics | Table WII |
| HUMAN ACTIVITIES (*Anthropology / Sociology / Demography*) | Human Community Types/Activities | Table HI | Human Community use of biosphere system components | Table HII |
| BIOTA (*Ecology*) | Types of Aquatic and Terrestrial Ecosystem | Table BI | Composition of biotic community<br>Patterns of biotic communities | Table BII |
| NEAR-SURFACE LITHOSTRATIRAPHY (*Geology / Geomorphology / Edaphology*) | • Rock Types<br>• Zonal Soil Types and Sediment Types | Table GI<br>Table SI | • Geological Characteristics<br>• Soils and Sediment Characteristics | Table GII<br>Table SII |
| TOPOGRAPHY (*Geography*) | Topographical Categories | Table TI | Topographic Characteristics | Table TII |

Notes to Table B1: GEOGRAPHICAL EXTENT and LOCATION are outside the classification scheme; their implications are propagated through the whole system identification and description process.

Natural correlations or dependencies between different biosphere system components (principal components and/or principal component types) can be identified, which provide overall coherency and justification for the assumptions that are made. Hence, for example, for a given climate type, the corresponding natural vegetation and soil types can be broadly defined using generally accepted relational schemes (see Table RTI of Annex BI). Such an approach allows for completion of biosphere system component identification in situations (assessment contexts) where no other more specific or verifiable information is available. The classification schemes given in Annex BI are offered as practical and useful, but alternatives could be used.

The starting point in identifying and justifying representative biosphere systems to support assessments for long-term releases tends to be decisions relating to the type of climate and human activities in relation to the environment. Soils, vegetation and certain aspects of human behaviour are all influenced strongly by climate. Therefore, in identifying the ecosystems that are to comprise an assessment biosphere, assumptions relating to climate will usually be a primary concern. Similarly, assumptions related to human activities will also be of major importance. This is because human communities can have a strong influence on the type of environmental system that is present and also because radiological exposures will depend on what people are assumed to do. Such assumptions should be consistent with the context of the assessment. They will represent primary drivers in the biosphere system identification and description process.

The manner and extent to which biosphere resources from a specific region are exploited by human communities will depend on the type of ecosystem and the degree of ecosystem management. Such interactions will, in turn, produce an effect on the environment, ranging from little or no impact to a marked change from the natural conditions. However, if the assessment endpoint is the radiological impact on humans, then some degree of human/biosphere interaction has to be assumed, at least in order to identify exposure pathways.

Depending on the assumed degree of human control or management over the biosphere system, the decision line for the process of system identification can be driven in one of two ways. If strong control or management by the human community over the biosphere system is assumed, this will be a necessary prior assumption, leading to the identification of other biosphere system components. Alternatively, if only weak control or management over the system is assumed, the system identification process can be driven by assumptions relating to climate.

#### B3.1.2. Step 2: Consideration of biosphere system change

It is recognised that biosphere systems are intrinsically dynamic (for example sedimentation in a water body, or the meandering of a river). In some systems, the combination of processes responsible for dynamic behaviour may (over time) be in balance and the biosphere system can then be considered to be in a state of dynamic quasi-equilibrium. For example, the sedimentation rate in a water body may be equivalent (over a given time period) to a rate at which sediment is removed by erosion or dredging rate. It is possible to represent biosphere systems, or sub-systems, where dynamic equilibrium is maintained as being time invariant: the dynamic processes operate (and contribute to contaminant migration and accumulation) but no apparent overall change occurs. However, if the processes responsible for mass transport in the biosphere system are assumed to be in dynamic equilibrium, it is important to ensure that the spatial and temporal frame, within which the assumption of equilibrium is valid, is explicitly stated.

Often, however, the intrinsic dynamics of the biosphere system are not in equilibrium, or the system may be influenced by agents of change that originate outside the immediate domain of interest for the purpose of radiological assessment. Such mechanisms can then result in fundamental changes to one or more biosphere system components e.g. the configuration and location of the water bodies may change with time.

Changes can occur over different temporal and spatial scales. Some, such as the clearance of woodland and its replacement by farmland, might occur over relatively short timescales. Others, such as the natural in-filling of a water body and associated ecosystem successions, may occur over longer timescales and can be considered to be gradual. The detailed consideration of such biosphere system change in the long-term has inherent and irreducible difficulties. However, there are different alternatives to be considered, which are developed further below, following the scheme represented in Figure B2.

*B3.1.2.1. No biosphere system change*

The assessment context may sometimes specify whether biosphere system change needs to be considered. If the assessment context states that system change does not need to be considered, then the use of a time invariant (constant) biosphere system, or alternative systems, is appropriate. The biosphere system(s) identified through the review of the assessment context (Step 1) can then be used to represent the unchanging biosphere. The system can then be described according to the approach given in Section B4.

***See Box 2 of Figure B2:*** *The biosphere system to be described is a constant biosphere system in which no biosphere system change is considered.*

This approach has previously been used in biosphere assessment for a number of HLW disposal concepts, for example the Electric Power Research Institute (EPRI) assessment of Yucca Mountain (Smith et al., 1996). It has the advantage of simplicity and provides an illustration of the consequences that might arise at the time of radionuclide release from the geosphere into the biosphere. However, it does not necessarily represent the range of systems that might exist during the time of the release for a particular site, or address issues associated with the sequence in which change may take place.

*B3.1.2.2. Biosphere system change*

If there is no explicit guidance from the assessment context, or if the assessment context expressly requires biosphere system change be considered, the following questions need to be addressed:

— what are the relevant mechanisms causing environmental change?

— what are the potential impacts of the resultant environmental change on the biosphere system?

When considering these questions, relevant information from the assessment context, in particular the timeframes of interest and the nature of the assessment end-points, should be reviewed, alongside basic hypotheses relating to the way in which potential exposure group(s) will be defined. This will help to guide identification of the relevant mechanisms for change and description of their impacts on the biosphere system for the case under consideration. In practice, some biosphere system components may be assumed to evolve with time, whereas others will be taken to remain in dynamic equilibrium. Such ‘mixed’ approaches are included under the general heading of biosphere system change.

*Step 2.1: Identification of mechanisms causing environmental change*

Apart from processes, such as erosion and sedimentation, that are internal to the biosphere system, the external driving mechanisms responsible for environmental change can be divided into natural mechanisms (long-term landform and climatically controlled environmental changes) and human actions.

The influence diagram shown in Figure B3 provides a hierarchical illustration of the relationships between different mechanisms that together, over various timescales, may be capable of modifying the features and characteristics of a given biosphere system (see subsection B3.2). Because such sources of change will typically have their origin outside the restricted domain that is of interest in describing an assessment biosphere, they are identified for convenience as External FEPs, or EFEPs. The influence diagram representation is intended to promote identification and analysis of relevant interactions between EFEPs, which is important in developing a coherent picture of their combined impact on the future evolution of the system.

This schematic model provides for clear identification of the primary system drivers, or initiators of change (shown in **bold** in Figure B3), whose effects are then propagated through the External Environment. A specific point of note in this context is that one potential mechanism of landform change (regional isostacy) can be both an initiator of change (in so far as it may be a element of the present-day regional context) as well as a response to other changes (such as ice-loading).

Consideration of mechanisms of change and their associated impacts on the biosphere system (Step 2 of the procedure summarised in Figure B2) can then be undertaken, first via systematic screening of system drivers and then by evaluating the importance of links between EFEPs according to the particular assessment context under study. This allows an assessment-specific version of the influence diagram to be constructed, as a model of the relationships between EFEPs relevant to that assessment. Sub-section B3.2 elaborates on mechanisms of change and their potential influence on the biosphere system components.

Whereas the regional response to changes occurring on a global scale may differ from one location to another, according to specific features and inherited characteristics of the landscape, global changes themselves can be characterised (e.g. through their time sequencing and magnitude) independently of any particular site or region. Hence, in developing practical descriptions of the mechanisms of biosphere system change and their effects, it can be helpful to make a distinction (as shown in Figure B3) between:

- the main time-dependent drivers of environmental change, typically operating on a global scale (including both continuous change and sudden or intermittent events); and
- the response to such drivers within the regional landscape.

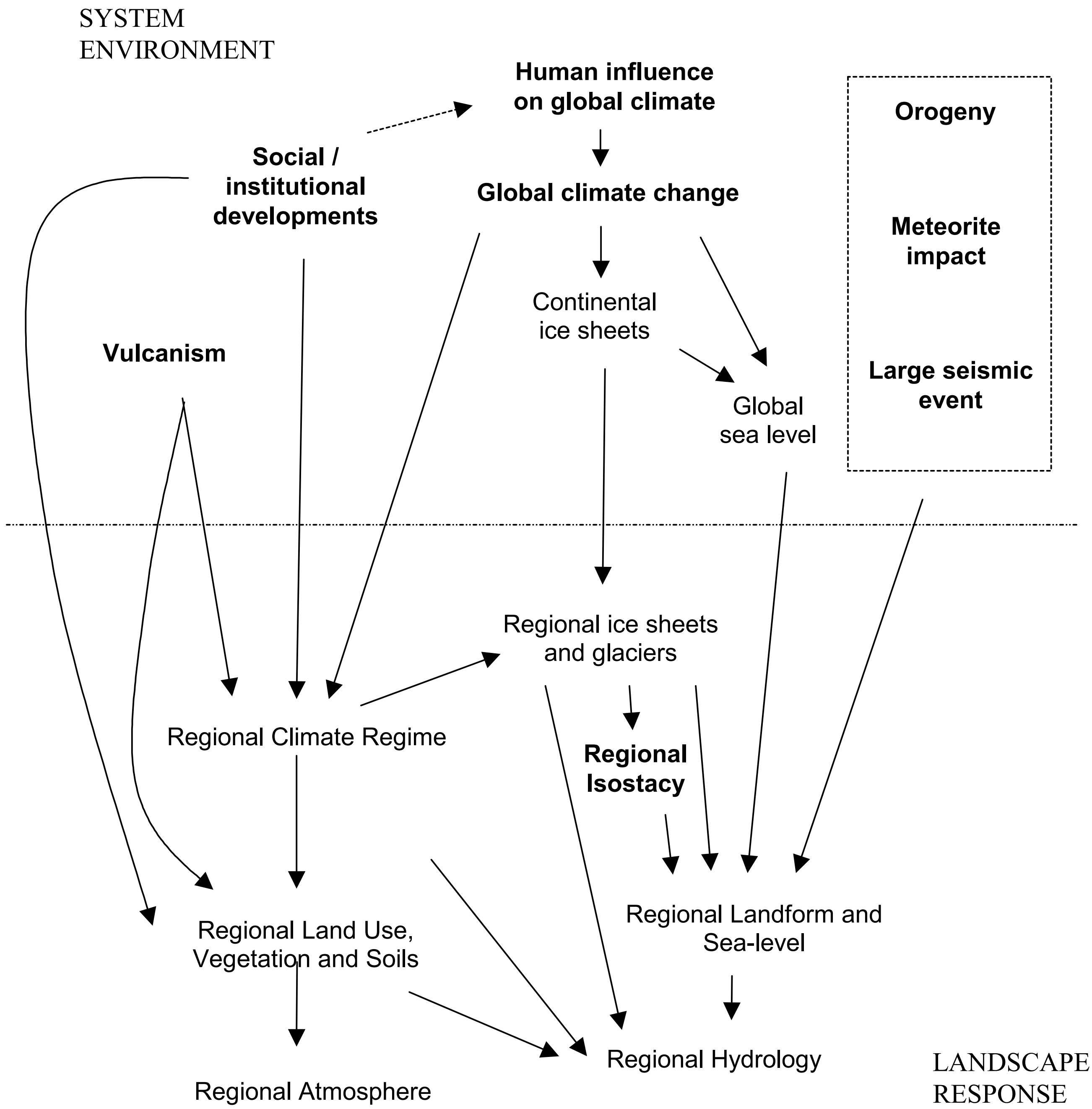


*FIG. B3. Influence diagram representation of EFEPs and their relationships.*

*Step 2.2: Identify potential impacts on the biosphere system*

Biosphere system changes of potential relevance to long-term radiological assessment can be defined through consideration of the way in which biosphere system components respond to the changing landscape. Hence, drawing on consideration of changes occurring at a regional scale, it is necessary to consider how such changes influence the identification and description of the assessment biosphere. This requires consideration to be given to the internal dynamics of the process system, taking account of external influences on the system as the landscape evolves.

It is not easy to draw an absolute boundary between the assessment biosphere system and its regional context[1], owing in part to the particular framework adopted within the BIOMASS Methodology for identifying biosphere system components. However, any systematic approach will inevitably involve some form of sorting or disaggregation scheme, and the current procedure is believed to provide a suitable working basis for applying the underlying principle that adequate justification should be provided for the assumptions adopted in defining an assessment biosphere. A general mapping of the relationship between principal components and characteristics of the biosphere system and the corresponding properties of the regional landscape is shown in Figure B4.

| Principal Components of the Biosphere System | Characteristics | Corresponding Regional Landscape Properties |
|---|---|---|
| Local Climate | Rainfall, Temperature, Windspeed, Solar Radiation | Regional Climate Regime<br>Regional Landform<br>Regional Land Use |
| | Atmosphere Characteristics | Regional Atmosphere |
| Geology | Unconsolidated Stratigraphy and Stratification | Regional Climate Regime<br>Regional Landform<br>Regional Hydrology |
| Soils and Sediments | Soil and Sediment Characteristics | Regional Hydrology<br>Regional Land Use, Vegetation and Soils |
| Topography | Relief, Altitude | Regional Landform |
| Water Bodies | Flow Rate, Water Level, Suspended Load | Regional Hydrology<br>Regional Landform |
| | Ice Sheet Characteristics | Regional Ice Sheet and Glaciers |
| Human Activities | Human Behaviour Characteristics | Regional Climate<br>Regional Land Use, Vegetation and Soils |
| Biota | Ecosystem Community Characteristics | Regional Land Use, Vegetation and Soils |

*FIG. B4. Identification of Relationship between the Principal Components of the Biosphere System and Regional Landscape Properties. The principal component 'near-surface lithostratigraphy' has been split into 'geology' and 'soils and sediments'. This allows a clearer explanation of the interactions in Figure B5.*

[1] For example, the 'boundary' between regional climate and that associated with the assessment biosphere is somewhat artificial, particularly as climate is itself a form of boundary condition for other components of the assessment biosphere. But localised climate conditions can also be affected (in principle) by other mechanisms within the biosphere system itself, such as the creation of local microclimates within greenhouses and other buildings, so some form of conceptual distinction is appropriate. Likewise, the role of topography as a component of the assessment biosphere is perhaps difficult to distinguish from regional landform in so far as its role is to provide a coherent context for other components of the system and their assumed properties. However, a key aspect of the system description is also the assumed spatial scale and configuration of its main components. Hence, in so far as topography describes "the relative positions of natural and man-made features", it therefore plays a distinctive role as a component of the assessment biosphere.

Because of the strongly-coupled nature of interactions at the temporal and spatial scales relevant to describing the assessment biosphere, a practical approach is to use an interaction matrix (IM) representation of the dynamics of the biosphere system, based on interactions between biosphere system components, as the basis for considering possible changes. Modifications to the characteristics of leading diagonal elements of the IM, as a result of the action of regional-scale EFEPs, may be propagated through the system by tracing pathways of influence via off-diagonal elements of the matrix. A generic IM description of biosphere system dynamics, for use as a tool to investigate the internal dynamics of the assessment biosphere, is provided in Figure B5.

*Step 2.3: Identify qualitatively different possible "futures"*

In practical application of the BIOMASS Methodology, it is envisaged that FEPs associated with off-diagonal elements of the IM would be highlighted (as appropriate) in accordance with knowledge and understanding of the importance of the phenomena they represent as intrinsic mechanisms for change for a specific biosphere system. These can then be translated into descriptions of the sequence of change within the biosphere system, in response to changing boundary conditions.

It should not be forgotten that the characteristics of biosphere systems can also change as a result of disequilibria associated with their intrinsic dynamics (e.g. as a result of aeolian or fluvial erosion and deposition processes), regardless of any 'external' effects. In describing assumed change and its potential contribution to radiological impact within the assessment biosphere, it may be equally important to account for such intrinsic phenomena (summarised in the interaction matrix, Figure B4) as it is to consider global change and its expression in the regional landscape.

Narrative descriptions of regional landscape evolution in response to global system drivers thus provide an evolving site context to guide the identification and description of the assessment biosphere. However, the issues involved in defining a representative assessment biosphere are not restricted to consideration of physical changes to the landscape. Just as is the case for time-independent systems, identification and description of the assessment biosphere also involves consideration of the assumed geosphere-biosphere interface and source term (defined – along with the site context – as part of the overall assessment context). Hence it is important that consideration of change within the assessment biosphere should also takes account of the changing regime for radionuclide release, according to the projected response of the overall disposal system to initiators of change at a regional scale. Other relevant guidance provided by the overall assessment context also includes the timeframes of interest and the nature of the assessment end-points that are to be determined.

| | | | | | | |
|---|---|---|---|---|---|---|
| Climate / | Weathering | Meteoric erosion | Level changes (e.g. evaporation, storm events) Deposition Freezing | Deposition Erosion Conditioning and moisture content (e.g. evaporation, freezing) | Environmental conditioning | Defines natural climax ecosystem, Affects transpiration rate. Storm damage |
| Contribution to dust load from eroded surface material, radon and other gas release | Geology | Definition of relief | Defines groundwater flow system and chemistry | Contribution to mineral composition (by weathering), gas release to soil/sediment | Availability of mineral resources. Type of geology affects construction practices | Nutrient support for microbial populations |
| Aspect effect on wind and insolation. Altitude effect on wind speed. Relief effect on boundary layer structure | No effect | Topography | Defines geometry (e.g. catchment areas, coastline) and hydrology (including mixing of meteoric and ground water) | Defines geographical extent relative to water bodies. Slope affects erosion rate and drainage characteristics | Relief affects size and type of community (e.g. capacity to develop agricultural systems and other land uses) | Relief affects characteristics of natural systems |
| Large water bodies influence seasonal temperature and humidity variation, local source/sink for heat and moisture | Erosion and dissolution (e.g. to form karst systems, geochemical reactions, freeze/thaw) | Erosion and dissoluton (e.g. downcutting of river bed, meandering, coastal processes) | Water Bodies | Sedimentation, erosion, mixing and suspension. Chemical conditioning by exchange with porewater. | Source, quality and quantity affects sustainability of community, recreational activities. Contribution to trace elements in diet | Source, quality and quantity affects type and behaviour of natural communities |
| Soil gas exchange with atmosphere | Diagenesis | Soil and sediment deposition influence the geometry (e.g. lake infilling, meandering and delta formation) | Contribution to sediment load. Chemical conditioning of meteoric water. Effect on flow field. Permeability of horizons contributes to geometry | Soil / Sediments | Soil moisture characteristics, structure and mineralogy affect potential utilisation. Source of fuel (peat) | Soil moisture characteristics, structure and mineralogy affect development of natural communities |
| Pollution, Creation of microclimates (buildings etc) | Quarrying and mining activities | Ground levelling | Hydrochemical conditioning (e.g. water treatment, waste water disposal). Extraction. Dam building. Augmentation | Agricultural practices, Dredging. Drainage systems | Human Community | Agriculture. Genetic manipulation. Population / ecosystem modification |
| Atmospheric composition (e.g. pollen and gas release). Microclimate development (e.g. wind break, boundary layer) | Biogeochemical conditioning by microbes | Effects assumed to be insignificant | Conditioning of flow, particulate load and hydrochemistry | Bioturbation. Conditioning, stabilisation & development. Control on moisture content (transpiration) | Natural resources. Disease vector | Biota |

*FIG. B5. Generic Interaction Matrix describing 'Intrinsic' Biosphere System Dynamics.*

The key elements of Step 2 of the decision tree are therefore:

— Screen primary mechanisms for change based on their relevance to the assessment context, with particular reference to those EFEPs identified on Figure B3 as belonging to the System Environment.
— Identify possible time sequences of change to the System Environment, based on consideration of the attributes and characteristics (type, magnitude and timing of change) for the identified initiators, and propagating their influence through the upper part of the influence diagram.
— For each identified time sequence of interest, develop a coherent description of the regional landscape response by propagating projected changes to the System Environment through the lower part of the influence diagram, giving due consideration to disequilibria (leads and lags) in the response of the regional biosphere. One or more time series of broad-brush descriptions of the projected evolution of the landscape can then be defined.
— For each landscape evolution, relevant assessment context information relating to the source term and geosphere biosphere interface is then reviewed.
— One or more time series of assessment biospheres can then be identified and described, corresponding to each landscape evolution sequence, taking into account the intrinsic dynamics of the biosphere system and changes to its physical boundary conditions as a result of the evolving regional landscape.
— Finally, based on arguments relating to the projected behaviour of radionuclides in the evolving biosphere, consideration is then given to the potential advantages and disadvantages of simulating (within the assessment) the effects of transitions from one biosphere system to another, so that a preferred assessment approach can be defined. This 'sequential approach' is discussed in the next section.

### B3.1.3. Step 3: Representation of biosphere system change

#### *B3.1.3.1. Choice of sequential or non-sequential approach*

Choices about the way biosphere system change is represented within an assessment (Step 3 in Figure B2) should reflect the underlying assessment context, in particular the purpose of the assessment and the endpoints to be evaluated. Selection of a preferred approach will depend on understanding inter-relationships between various timescales for change, not only within the biosphere system itself (in terms of the dynamics of mass fluxes) but also in respect of radionuclide dispersion and accumulation within the dynamic system. For example, if the emphasis is on providing indicators of the lifetime-average annual individual exposure, explicit representation of changes leading to fluctuations in radionuclide concentration on timescales of less than a lifetime may not necessarily be appropriate.

The main choice of modelling approaches is between a non-sequential and a sequential representation. These are defined as follows:

#### *B3.1.3.2. Non-sequential approach*

Taking account of the description of projected changes to regional landscape and to the corresponding source term, it may be possible to identify a finite number of discrete, quasi-equilibrium biosphere states, which are judged to be adequately representative of key stages in the evolution narrative. Time-invariant assessment biospheres corresponding to these quasi-equilibrium conditions may then be identified and simulated in such a way that they are independent from one another, with their projected sequence disregarded. A non-sequential approach will be appropriate in situations where radiological impacts associated with the assumed quasi-equilibrium state are not significantly affected by possible previous concentrations of radionuclides in environmental media.

| ***See Box 3 of Figure B2****: describe alternative non-sequential biosphere systems* |
|---|

*B3.1.3.3. Sequential approach*

The aim of such an approach is to provide for explicit representation of biosphere system change, either through simulating a sequence of discrete states or via quasi-continuous variation of the properties and characteristics of biosphere system components. It is particularly appropriate in situations where the judgement is made that accumulation of radionuclides at an earlier stage in the evolution narrative may have implications for the consequences at subsequent times after change has taken place. The sequential approach provides for assessment biospheres to have a "memory" of the distribution of contamination prior to and during the particular transition(s) they are intended to simulate.

| ***See Box 4 of Figure B2****: describe sequential biosphere systems* |
|---|

Whichever approach is taken, the development of an adequate representation of change should not necessarily depend on trying to provide a complete simulation of biosphere system evolution throughout the overall time frame of interest. Rather, the aim is to work from narrative descriptions of landscape evolution over that period in order to identify assessment biosphere systems that are sufficiently representative to provide an adequate measure of projected overall safety performance of the disposal system. This involves the use of scientific understanding and judgement to highlight periods of time that are expected to be of particular interest or concern. For example, the identification of particular transitions, projected to occur within a specific time period, as being of interest or potential importance does not imply a need to represent the complete future evolution of the biosphere using a sequential approach. In such situations, it may be sufficient to consider the dynamics associated with a specific transition, or series of changes, in a separate calculation, the results of which could then be considered alongside results from identified non-sequential 'system state' models.

It is not easy to draw an absolute distinction between 'continuous' and 'discrete' (step-wise incremental) representations of sequential change. Indeed, any dynamic representation of a changing system will tend to introduce some discontinuities, effectively collapsing the assumed timescale of system response to zero over the period in which a defined change takes place. The important consideration is to ensure that such discontinuities do not introduce unacceptable artefacts into the results of the assessment. The choice of appropriate time-steps in representing a sequence of system conditions might be considered as the temporal equivalent of grid refinement in spatial representations of flow and contaminant transport.

Explicit representation of change as a sequence of discrete biosphere system states will usually tend to overestimate the likely radiological consequences during the period in which the anticipated change actually takes place. For example, if a projected future fall in sea level is simulated as a step-change from a coastal to a terrestrial environment, the erosion of sea bed sediment and remobilisation of contaminants, resulting from coastal processes taking place as sea level fell, might not be properly taken into account. Hence it is likely that the potential radiological implications of reclaiming former bed sediments for use as arable land would be overestimated. Nevertheless, the more complex modelling requirements and judgements associated with representing biosphere change more realistically as a continuous variation may only be justified if the assumption of a sequence of discrete states found to give rise to excessive overestimates of environmental impact.

## B3.2. MECHANISMS OF CHANGE AND THEIR POTENTIAL RADIOLOGICAL SIGNIFICANCE

Mechanisms of biosphere change generally fall into two main categories: those that are external to the system of interest (identified as EFEPs – see Figure B3) and those that are intrinsic characteristics of the biosphere system (see Figure B5). The aim of this section is to provide a summary of different types of change, and to identify how they might play a significant role in the definition of assessment biospheres. For any given assessment context, the arguments used to screen particular mechanisms of change and their effects will depend on the magnitude and timing of changes and their effects, as determined by the basic premises of the assessment, including any site-specific factors. The general overview presented here should help to guide decision making by highlighting the potential radiological importance of different causes of biosphere change.

### B3.2.1. External factors relevant to regional landscape change

#### *B3.2.1.1. Background*

The influence diagram in Figure B3 illustrates the hierarchy of relationships and dependencies between potentially relevant External FEPs (EFEPs) and their influence on the boundary conditions of the Process System in which radionuclide transport and radiological impacts are assessed. In general terms, the major drivers of system change are seen to exert influence initially at a global scale. This influence is then propagated down to regional and local scales and it is at these smaller scales that changes to the biosphere system are defined and their radiological significance needs to be considered.

An important intermediate level of the description of change within the EFEPs system relates to the regional landscape in which the assessment biosphere is assumed to be embedded. The present day landscape can be characterised (e.g. in terms of landform, hydrology and land use) from observations within the region of interest or (for a more generic assessment) on the basis of appropriate hypotheses regarding the setting in which the radiological impacts of potential releases will be determined. EFEPs operating at the regional and local level are then assumed to modify this landscape over time, providing a context in which the temporal evolution of the boundary conditions on the Process System can be specified.

A significant consideration in the above is that the landscape description is developed on a larger spatial scale than that of the assessment biosphere. This is necessary so that it can include a characterisation of those factors that influence the boundary conditions of the assessment biosphere. For example, the subsurface hydrological conditions that determine radionuclide transport within the assessment biosphere itself may need to be defined on a spatial scale of only a few kilometres. However, in setting those boundary conditions, consideration may need to be given to the geometry, hydraulic properties and recharge/discharge characteristics of the regional aquifer. This means that the area of interest in describing landscape evolution could encompass the wider region in which a disposal facility is situated from the local uplands to either a major river or the coastal zone of discharge.

In the following discussion, the emphasis is on broad issues and considerations involved in developing a description of landscape evolution, rather than focusing on the specific technical details of particular approaches that might be used. It is recognised, however, that a wide range of techniques may be relevant, from systematic qualitative reasoning to more detailed, mechanistic modelling of processes and their effects.

### *B3.2.1.2. Global climate change*

Scientific understanding of global climate change during the Quaternary period suggests that it can be broadly characterised in terms of cycling between glacial and interglacial episodes, with a characteristic periodicity of approximately 100 000 years. The range of average global land surface temperature between the coldest and warmest stages of the cycle is believed to be in the region of 10 to 15° C. Indices of global climate variation, based on indicators of palæoclimate (such as variations in $^{18}O/^{16}O$ isotopic ratio ($\delta^{18}O$) in materials from cores taken from ocean sediments and continental ice sheets e.g. (Thorne et al., 1995; 1997)) indicate that present-day global climate is close to a maximum in the cycle.

At a global scale, past changes in climate have resulted in the advance and retreat of continental ice sheets (as indicated in Figure B3). The period of the Late Devensian Glacial Maximum (c.25,000 to 14,000 years before present) was characterised by extensive continental ice sheets in the Northern Hemisphere – the Laurentide ice sheet in North America and the similarly massive Fennoscandian ice sheet in Europe (Thorne et al., 2000). Continental ice sheets of similar extent were associated with cold episodes earlier during the Quaternary period, and modelling studies (Burgess, 1998) suggest that they are likely to develop again in the future.

The development of continental ice sheets could have direct effects at the scale of regional landscape evolution e.g. if the region of interest were covered by an ice sheet or located close to an ice margin, where the climate and hydrological regimes could be affected by the presence of ice. Additionally, the development of extensive ice sheets could have indirect effects on characteristics of the regional landscape because of the degree to which their development and retreat influences global sea level. To illustrate the magnitude of this effect, global sea levels at the Late Devensian glacial maximum were about 130 m lower than at the present day, owing to the large volume of ocean waters ‘locked up’ in the continental ice sheets (Thorne et al., 2000).

The cycle of global temperature change is far from being a simple harmonic variation; there are clear indications in the climate record of other cycles and variations occurring on a range of different timescales, some much shorter than 100,000 years. The long-term record can, at best, provide only an approximate indicator of the likely timescales and magnitudes on which future changes are likely to occur. Moreover, simple extrapolations cannot account for the long-term effects of possible perturbations to the cycle, such as forcing by anthropogenically-enhanced levels of greenhouse gases within the atmosphere.

Some investigators have attempted to reproduce variations in global climate using atmospheric circulation models driven by long-term variations in insolation, according to the Milankovich theory of precession of the Earth’s orbit around the sun. Such models, when calibrated against the palæoclimate record, can then be used to forecast the likely timescale on which future changes may occur (Gallée et al., 1991; Burgess 1998). According to such models, the next minimum in the natural global temperature cycle, corresponding to a glacial episode, is anticipated between 20,000 and 30,000 years after present. However, current studies using these models have also indicated that the human influence on global climate, through enhanced greenhouse gas levels, could give rise to long-term warming (by up to 6° C increase in global mean surface temperature) for a period of up to 10,000 years. One effect of such enhanced warming might be effectively to 'cancel out' the next anticipated glacial episode.

As a basis for describing climate change at a regional scale, however, it is important to have more than just a projection of long-term changes in global temperature and ice sheet extent. In principle, it would be useful to be able to define global climate at a spatial resolution similar to that adopted in the current generation of General Circulation Models (GCMs) i.e. a few degrees of latitude and longitude. Techniques proposed for doing this include calibration schemes based on regional indicators of palæoclimate, such as long-term pollen and insect records, as well as modelling methods for matching GCM simulations to long-term climate evolution models.

Global climate characteristics defined at a resolution of a few degrees then need to be downscaled to the region of interest. As part of the downscaling process, or at the level of global climate representation, it is also relevant to account for regional factors such as the influence of sulphate aerosols. In applying downscaling methods, attention also has to be given to factors such as the location of ice-sheet margins and the position of coastal boundaries relative to the region of interest. This is because special climate conditions exist in ice-sheet marginal areas and also because the location of a site relative to coastal margins influences the degree of continentality of the climate. This means that the regional climate regime has to be defined not only in relation to global climate, but also with reference to the extent of regional ice sheets and glaciers, and in the context of regional sea level (as this affects the location of coastal boundaries).

*Changes in the regional climate regime*

Once an overall regional climatic regime has been established, consideration can be given to local perturbing factors. For example, social and economic developments may result in an increase in industrialisation of a region. Apart from larger-scale effects, such as the contribution to sulphate aerosol production (mentioned above), there are more localised effects e.g. the production of heat domes over cities, which can be factored in at this stage.

The potential radiological implications of changes to seasonal patterns of temperature and precipitation on a regional scale are various. It is not the intention here to provide an exhaustive list of the types of change that might occur, but selected examples include:

- warmer climate regimes may provide for a greater diversity of agricultural practice, as well as influencing human diet and behaviour (for example, changes in water consumption);
- colder climate regimes will tend to restrict the range of possible agricultural practices to crops tolerant of a shorter growing season, with increased emphasis (in communities dependent on local resources) on bringing animals inside during the winter, greenhouse cultivation and reliance on food products from natural and semi-natural ecosystems.

There may also be increased seasonal differences in surface hydrology (snow melt, ice dams etc.) and human behaviour (e.g. diet, time spent indoors or outdoors);

- more arid climate regimes imply a greater soil-moisture deficit and corresponding increased requirement for groundwater and surface water resources to be used in support of irrigation;
- more humid climate regimes may increase the availability of local water resources and rates of erosion, with the potential for increased dilution and dispersion of contamination.

Climate change and associated changes in vegetation are closely coupled to soil development. Vegetational colonisation of a regolith leads to the early stages of soil development, which in turn provides a changing substrate on which ecological succession occurs. Climate-dependent considerations include influences on rates of decay and decomposition of organic matter. For example, in some cooler climate regimes primary productivity may be relatively high, while decomposition rates may be restricted, leading to an accumulation of organic detritus.

*Changes in regional glaciation and presence of ice sheets*

Details of the geometry of ice sheets and glaciers at a regional scale (where they may occur) can be significant determinants of characteristics of the landscape. For example, in considering the geomorphological characteristics of a potential repository location in the UK, distinctions need to be made between different parts of the British Ice Sheet. During the Late Devensian period, this was, in fact, a part of the overall Fennoscandian Ice Sheet; however, the Scottish uplands were covered with ice more than 1 km thick, whereas only a relatively thin sheet of ice extended down the East coast and Southern England remained ice free. More local effects on geomorphology are also of relevance. For example, in West Cumbria, UK, consideration has to be given to time-dependent interactions between the regional element of the Fennoscandian ice sheet, extending from Scotland, and valley glaciers penetrating from the Cumbrian uplands (Thorne et al., 1997).

In defining the characteristics of ice sheets and glaciers, so as to evaluate their potential contribution to future landscape change, appropriate models may include mathematical representations of ice-sheet development and retreat, as well as field evidence for patterns of erosion and deposition created by ice sheets and glaciers in the past. At the regional scale, the formulation of scenarios describing time-histories of potential future landscape conditions is therefore likely to reflect information derived from both quantitative modelling and more qualitative, descriptive sources.

Regional ice masses may also have effects on both surface hydrology (e.g. giving rise to the development of outwash formations such as eskers in subdued landscapes or the development of pro-glacial lakes) and groundwater flows (through effects on recharge characteristics in areas covered by ice). Contamination accumulated in environmental media in earlier environmental conditions may be remobilised within the active surface environment adjacent to ice sheets and glaciers.

Periglacial effects such as permafrost can give rise to significant changes in the dynamic properties of the biosphere and groundwater systems. An example is the possibility of localised discharges of regional groundwater via gaps in the permafrost (known as taliks), where the comparative lack of dilution would mean that surface waters could be relatively highly contaminated. On the other hand, the surface conditions in permafrost environments tend to militate against the presence of local populations, making unlikely the exploitation of such surface waters as a resource. Moreover, any accumulated contamination in the vicinity of taliks is likely subsequently to be readily dispersed – either by glaciation (if the climate is cooling), or dilution associated with melting of the permafrost (if the climate becomes warmer).

*Isostatic effects*

On very long timescales, the elevation of the landscape is determined by an interaction between tectonic and denudational effects. Imposed on these long-term changes, shorter-term glacio-hydro-isostatic induced variations in elevation may occur as a result of ice and/or water loading. In particular, continental and regional ice-sheets will cause crustal depression beneath the ice, which may be more than a kilometre in thickness, together with compensating uplift in a forebulge beyond the ice margin. Hydroisostatic effects arise from the advance and retreat of the oceans on the continental shelves during glacial-interglacial cycles. Estimates of continental ice volumes suggest that overall changes in global sea level during the course of such a cycle can be up to about 130 m.

At equilibrium, the amount of isostatic depression beneath an ice sheet or coastal ocean can be approximately one third of its depth; however, timescales of thousands to tens of thousands of years are required for such equilibrium to be established. Hence it is possible that, as a result of glacial-interglacial cycling, depression and recovery can follow a time-dependent pattern of change that exhibits no stable equilibrium phase. Nevertheless, in considering potential landscape change for a given region, the short-term effects of ongoing isostatic change can be derived from characterisation of the rate of change, independently of detailed knowledge of the depth or extent of past ice sheet cover.

Differential changes in elevation can have an influence on regional drainage patterns, while general isostatic effects can influence the location of the coastline. This has implications for the level of the groundwater table. Isostatic uplift may also lead to a corresponding fall in the regional groundwater table, causing the drying out of lakes and wetlands.

*Changes in regional landform and sea level*

Erosion and deposition by glacial action have a substantial effect on landform. For example, ice advance during a single glacial episode in Northern Britain has typically resulted in removal of most of the pre-existing unconsolidated material. In retreat, the ice has then eroded some 20 m of the underlying parent material to create a new cover of sediment (Clayton, 1994). In the extreme, therefore, when ice cover extends over the whole region of interest, the biosphere system will be subject to gross disruption, with large-scale dispersion of existing contamination.

Both erosion and deposition processes may exhibit strong spatial distinctions, resulting in the classic landforms of formerly glaciated regions. Differential changes in landform and topography as a result of a glaciation can have major impacts on surface water flows, potentially altering the configuration of drainage basins and hence the directions followed by streams and rivers.

On timescales of tens to hundreds of thousands of years, regional sea levels are determined both by eustatic changes in global sea level and by glacio-hydro-isostatically induced changes in land elevation. In regions prone to glaciation, the interactions of global sea-level changes and isostatic effects can lead to complex patterns of regional sea-level variations, with the occurrence of sea-level stands substantially above and below that observed at the present day.

One potentially significant effect of changes to landform and regional sea level is movement in the boundaries for the surface hydrological system. Changing relief and base level will potentially have an effect on surface water flows rate and direction, as stream courses adapt to changing gradients. Under conditions where regional sea level is falling (either as a result of land rise or global sea level fall), a falling regional groundwater table may lead to the drying out of lakes and wetlands.

Sea level rise and fall also have an impact on flow in the regional groundwater system, particularly in coastal regions, where density gradients at the saline/freshwater interface may influence the location of discharge. In addition, the changing location of the coast can affect the type of biosphere system into which contaminated groundwater may emerge. For example, rising sea levels may result in contaminated groundwater discharges emerging in the marine environment, rather than to land. Conversely, with sea level fall, the previous sea bed may become exposed and reclaimed for various land uses. In such circumstances, however, the radiological significance of previous contamination of the newly exposed sea bed will be conditioned by erosive processes (e.g. caused by the effects of wave action) that may remobilise accumulated contamination in the dynamic coastal environment.

#### *B3.2.1.3. Earth processes and meteorites*

Global climate change, as influenced by social and institutional developments, is a continuous process that will affect the landscape through the various changes identified above. However, other EFEPs that may, or may not, occur in a particular regional context can also influence the landscape.

*Orogeny*

Orogeny, or the formation of mountain ranges by crustal deformation, can be classified as a global process, in so far as it arises on a large spatial scale and its origin is the consequence of global processes such as continental drift, driven by plate tectonics.

Orogeny is associated with regional uplift, generating a progressively greater erosional instability that results in enhanced denudation, typically on timescales of millions of years or longer. This can lead to the redistribution of eroded materials, potentially resulting in dispersion of environmental contamination. The radiological significance of such effects will depend on regional factors, such as the rate of uplift compared with the overall timescale of interest to the assessment. There may also be a potential for differential effects on topography at a regional scale, which could influence hydrogeology and, thereby, the location of the geosphere-biosphere interface.

*Vulcanism*

Vulcanism arises from global processes similar to those responsible for orogeny, occurring at plate boundaries or above upwelling mantle plumes. Indeed, vulcanism can be thought of as a component, or result, of fundamental orogenic processes. Hence, evaluation of the possible direct effects of vulcanism on regional landform can be effectively subsumed into the general treatment of orogeny, but the possible effects of volcanic eruptions on the regional climate regime and land use need to be considered separately.

In principle, major volcanic episodes can influence global climate. However, likely effects at the global scale are minor perturbations (short-term and of limited magnitude) compared with changes resulting from variations in solar insolation and changes in atmospheric greenhouse-gas concentrations. More localised effects of volcanoes on climate at a regional scale may include cooling as a result of ash and sulphate aerosol injection into the atmosphere. However, such effects are also transient and insignificant in their impact compared with the effects of global climate change. Indeed, natural variations in regional climate conditions on timescales of tens to hundreds of years may easily encompass any effects that may be directly attributable to vulcanism.

Ash deposition from volcanoes may effectively sterilise the surface environment through a transient effect on land use, vegetation and soils. This would imply much lower productivity and greater import of foodstuffs, water supplies etc. In extreme conditions, evacuation might take place. The recovery period following deposition of ash is potentially of more radiological interest, although the timescales associated with any transitional effects are expected to be relatively short compared with those of interest to long-term radiological assessment.

Clearly, in the extreme, the occurrence of vulcanism within the regional landscape itself would be a relevant consideration in describing long-term biosphere change. However, compared with the possible impact of regional magmatic activity on disposal system safety through its effects on engineered system performance and groundwater flow conditions, the radiological implications of associated changes within the biosphere (lava flows onto land or ice sheets) are likely to be of somewhat lower importance.

*Large seismic events*

Large seismic events are not expected to have more than a limited effect on regional landscape in most site contexts. However, it is not impossible for fault scarps of a few metres or so to occur as a consequence of a single event. Repeated large-scale fault movements are an integral component of orogeny and would be associated with multiple seismic events of varying magnitude. However, even the accumulated effect of multiple seismic events in a seismically active area (resulting in, for example, modified drainage patterns) may not be particularly significant from a radiological perspective. The main consideration in relation to possible seismic events occurring close to, or within, the regional landscape of interest is more likely to be their possible impact on groundwater flow patterns, through movement of faults and fractures, which might have an influence on the location of the geosphere-biosphere interface.

The occurrence of tsunami can be related to seismic events occurring under the ocean at the continental shelf. It is not necessary for such events to take place close to the region of interest in order to have an impact on a given landscape – tsunami are able to travel over distances of hundreds of kilometres before reaching land. In affected coastal areas, marine transgressions will lead to salinity contamination, with consequent impacts on water resources, in particular. For example, there might be a switch from the exploitation of surface waters (such as lakes) to rivers and deep aquifers.

*Meteorites*

Meteorite impacts have the potential to generate landscape features such as craters. They can also modify the properties of the rocks e.g. through deep fracturing, thus changing their propensity for erosion. In humid regions, the crater formed by a large meteorite might become filled with water.

The principal basis for screening meteorite impact from further consideration as part of a long-term assessment is its likelihood of occurrence within the region of interest, which is not strongly dependent on location. The type of event of most interest from a biosphere perspective would be one of medium size (such as, for example, the Tunguska event in Siberia) causing impacts on vegetation over a substantial area, with potential consequent effects of enhanced erosion and redistribution of biosphere materials. The radiological implications of such an acute event (e.g. in terms of redistribution of contamination) could be transient, occurring over relatively short timescales compared with those implicit in computing lifetime annual average individual doses for comparison with radiological protection standards. However, there could also be longer term implications, especially if the geosphere-biosphere interface is affected.

*B3.2.1.4. Social/institutional developments*

There is no obvious 'model' for describing social and institutional developments and their effects on regional landscape and biosphere systems. Where the assessment context dictates that future environmental change should be taken into account, an appropriate response is to consider human behaviours based on present-day (or, if available, historical) land-use and resource exploitation practices in analogue regions, selected for the representativeness of their climate and landform characteristics. When describing the biosphere system identified at this stage, Table HIIa (Annex BI) can help to select what human influences can be of relevance in terms of system changes.

The convention for present-day releases is that extremes of behaviour do not need to be considered in radiological assessments in order to demonstrate adequate protection of individuals. This implies that emphasis can justifiably be placed on developments in which changes to the biosphere system reflect reasonable utilisation of the future biosphere (i.e. taking account of resource availability and nutritional needs etc.) in the region of interest.

The potential for human actions to cause acute changes to the environment with long lasting consequences (e.g. land reclamation, earthworks, forest clearance) needs to be recognised. In so far as the radiological implications of the change itself (e.g. in terms of redistribution of any pre-existing contamination) are likely only to be transient, it may be possible to justify excluding representation of the transition itself from the biosphere assessment basis. It remains to be formally investigated whether or not the results of such changes could be of potential radiological importance and, if so, whether they might reasonably be considered as a basis for Reference Biospheres.

*Land use*

Maximum reasonable utilisation of local resources within the biosphere is often taken to imply an agricultural system, to the extent that this is sustainable, or the exploitation of natural resources through hunting and gathering. Even if present-day human activities at a site are not consistent with such assumptions, it will normally be appropriate to consider a range of past sustained land uses in the region of interest (or present-day community systems in appropriate analogue regions) as a basis for characterising future biosphere systems.

Patterns of vegetation and associated soil characteristics can be influenced by, or indeed almost completely determined by, land management practice. Land use, in conjunction with vegetation patterns and soil characteristics, has a major influence on regional hydrology by determining how precipitation is partitioned between surface flow, interflow and groundwater recharge. Surface and subsurface patterns of flow and the shape of the land surface then determine how the drainage network develops. The nature and characteristics of the drainage network are then, in turn, factors affecting ongoing erosion and deposition processes.

*Regional hydrology*

Direct influences of human activities on regional hydrology may include, among other things, artificial drainage systems, pumped water abstraction, construction of impermeable surfaces, dam building or the artificial maintenance of surface water courses through canalisation. Any future developments of this kind would need to be consistent with the regional biosphere characteristics and the assumed requirements of the human community. Where sufficiently extensive, such developments have the potential to affect dilution rates for contaminants released to the biosphere, and to alter patters of recharge and discharge, thereby modifying the geosphere-biosphere interface.

*Regional climate*

Industrialisation and urbanisation within a region may contribute to sulphate aerosol production or more localised effects, such as the production of heat domes over cities. As a result of such anthropogenic effects, climate parameters associated with a region may differ slightly from those determined by downscaling from models for global climate change. Nevertheless, such effects are expected to be small compared with the uncertainties associated with attempting to define precise seasonal temperature and precipitation characteristics for any given climate regime.

### B3.2.2. Internal factors relevant to regional landscape change

#### *B3.2.2.1. Background*

The development of a coherent description, or set of alternative descriptions, of the possible evolution of the regional landscape involves not only consideration of the possible influence of external, global factors, but also the dynamics associated with processes that are inherent to the biosphere system itself. Changes to the properties and characteristics of the regional landscape, caused by external factors, therefore need to be propagated through the biosphere according to the coupled system of relationships illustrated in Figure B5. Moreover, regardless of any 'external' changes, biosphere system characteristics may change as a result of disequilibria generated by the intrinsic dynamics of the system (e.g. as a result of aeolian or fluvial erosion and deposition processes).

Some key issues associated with the propagation of change through the biosphere are highlighted below, taking each biosphere system component in turn. In practice, interpretation of the effects of such processes to provide a self-consistent narrative may involve a range of techniques, from qualitative reasoning to more detailed quantitative understanding of processes and their effects. The aim here is not to provide a detailed analysis of how such processes might be assessed for a given region, but simply to illustrate how the interactions represented in Figure B5 are able to provide for systematic consideration of the coupled relationships between biosphere system components.

#### *B3.2.2.2. Climate/atmosphere*

External factors that can affect the climate and atmospheric properties of the biosphere system include changes to the regional climate regime, landform (e.g. moderating influence on climate of coastal waters) and regional land use (e.g. industrial emissions and heat sources) (see Figure B4). In so far as climate characteristics are capable of conditioning human behaviour and ecosystem development, descriptions of regional climate change need be extended to describe their influence on assumed human communities and biota within the biosphere. As indicated above, an appropriate means of doing this in a coherent fashion can be to develop system descriptions on the basis of observations from representative regions with appropriate climate and landform characteristics.

In addition, it is necessary to consider whether specific processes related to climate characteristics can affect other elements of the process system. Some dynamic effects associated with 'equilibrium' climate conditions (e.g. seasonal and diurnal change) occur on very short timescales and it would not normally be appropriate to describe their effects explicitly as part of the narrative of biosphere system change. However, the net effect of short-term changes (such as storm events and freeze/thaw processes) may be a gradual change in the characteristics of other biosphere system components such as soil and rock properties, topographic gradients and the geometry of water courses. Moreover, if regional climate characteristics change, then the rate or direction of change of the properties and characteristics of other biosphere system components may also be altered.

Finally, it is also relevant to consider how local climate and atmospheric composition may change as a response to changes in other biosphere system components. For example, the construction of buildings or use of greenhouses for cultivation (i.e. change to human community characteristics) can give rise to localised microclimates that are significantly different from prevailing regional climate conditions. Localised microclimates and alterations to atmospheric composition may be associated with ecosystem change (e.g. through the development of forests) or changes to topography and water bodies.

#### *B3.2.2.3. Geology*

Properties and characteristics of the near-surface geology are not intrinsically dynamic, except in so far as they may be affected by the continuous processes of weathering and erosion. The stratigraphy and stratification of the near-surface, unconsolidated geology can, however, be affected by changes to the regional climate regime, regional landform and regional hydrology (see Figure B4). Such changes may have implications for topographic relief, the physical and geochemical properties of the groundwater flow system, as well as the mineral composition of soils within the biosphere system.

#### *B3.2.2.4. Topography*

The topographic characteristics of a biosphere system are not intrinsically dynamic, except in so far as relief, as well as the geometry of water courses, may change over time in response to wind and water-driven erosion processes within the biosphere. In addition, relief and altitude may also be affected by more widespread, regional changes in landform. Nevertheless, processes such as coastal erosion and river meander can be important considerations in describing the long-term evolution of the configuration of boundaries between the terrestrial and aquatic environments, irrespective of global EFEPs, such as climate and sea level change.

Topography may also change as a response to changes in other biosphere system components. In particular, human actions may be responsible for changes to topography, for example through land reclamation, the development of earthworks and excavations and canalisation of rivers. This could, in principle, be extrapolated to the conclusion that the overall configuration of biosphere system components may be influenced so much by human actions that it ultimately bears no resemblance to that expected to evolve as a result of natural processes. Whether or not the potential for such artificial changes is taken into account in the identification and justification of the biosphere system depends on judgements about their likely relevance to the underlying assessment context.

*B3.2.2.5. Water bodies*

Water bodies can be an important dynamic part of the biosphere, representing a major contribution to mass flux. The presence of large water bodies may have an influence on the local climate regime. Erosion and sedimentation processes can be important contributors to the long-term evolution of a landscape, irrespective of other (external) sources of change. The rate at which these processes occur is determined both by the nature of the existing landscape e.g. in terms of its topography and lithostratigraphy, and by climatic conditions.

For example, cliff erosion rates at the coast can be as much as a metre per year or more. River meander, generated by a combination of sedimentation and erosion processes, can be an important process for redistribution of sediments in regions of low relief. The same processes govern the dynamics of estuary development, with the added influence of tidal forces on coastal currents and sediment transport.

Describing the evolution of a biosphere system needs to take account of the response of water bodies to external change, and the resulting effects on the dynamics of erosion and deposition within the biosphere system. Properties of the regional landscape that can have a direct effect on the flow rate, level and suspended load of water bodies include changes to the regional hydrological regime and landform (see Figure B4). The hydrological system may respond to external change in many ways. For example, as a result of changing base levels, river incision can take place to a depth of some tens of metres below a predefined palaeosurface on timescales of as little as a few thousand years. Similarly, sea level rise can have a marked influence on projected rates of coastal erosion.

*B3.2.2.6. Soil/sediments*

Properties and characteristics of soils and sediments are not intrinsically dynamic, except in so far as they are affected by the continuous processes of weathering and erosion. These processes contribute to the sediment load in surface water bodies. The composition, texture and stratification of soils and sediments can, however, be affected by changes to regional hydrology, land use and vegetation (see Figure B4). Such changes may, in turn, have implications for land use and the types of flora that may be supported within the biosphere system.

*B3.2.2.7. Human community*

Activities and resource exploitation practices undertaken by the local human community can have a major influence on the composition of the biosphere and the configuration of the biosphere system components. Engineering activities may result in changes to water courses and alterations to topography. Ecosystems may be intensively managed by agricultural communities, resulting in the introduction of alien species through animal husbandry and the development of a patchwork of vegetation monocultures. The construction of buildings will give rise to controlled microclimates that differ significantly in terms of atmospheric quality, temperature and humidity from the outside atmosphere. Hunting, fishing and pest control may have a significant influence on the populations of natural species.

The extent to which human activities are assumed to influence the evolution of the biosphere system will depend on fundamental assumptions relating to the type of community that is present and its technological capabilities. However, there may be some conditioning of the type of activities according to the prevailing climate characteristics and their influence on the natural productivity of the biosphere system.

*B3.2.2.8. Biota*

Ecosystem community characteristics will largely be defined by land use and vegetation characteristics on a regional scale which, in turn, depend on climate conditions and soil type. Ecosystem dynamics dictate that populations will fluctuate naturally with time in response to the natural processes of change, disease, predation and consumption within the foodweb. Individual species and communities will also respond to changes in regional conditions.

Biota may act dynamically within the biosphere, insofar as population migrations cause changes with time of the types of flora and fauna that are present. Some biotic activity (e.g. burrowing) can contribute to the turnover of bulk material (and hence contamination) within soils and sediments.

## B4. DESCRIPTION OF THE BIOSPHERE SYSTEM(S)

### B4.1. INTRODUCTION

A biosphere system description, taking account of the overall assessment context, can be developed by building on the initial identification of biosphere system components (Section B3). The development of a conceptualised description of the biosphere system consists of three main parts:

- identification of significant characteristics of each biosphere system component, taking account of their relevance to the underlying assessment context;
- determination of phenomena relevant to providing a suitable description of the dynamic behaviour of the biosphere system for the purposes of radiological assessment. These phenomena may be intrinsic to individual biosphere system components or associated with the interactions and relationships between different biosphere system components;
- description of the configuration of, and connectivity between, different parts of the system, taking account of the part they would play in the migration and accumulation of contaminants within the biosphere system.

Even though some of the biosphere characteristics correspond to dynamic processes, the procedure for development of a biosphere system description relates to a fixed point in time or to a non-evolving biosphere. If the assessment context requires that biosphere change should be addressed, then the system description would need to include a discussion of the rate of change of the individual characteristics for each affected biosphere system component. However, the time scales for change (rate of change, period of change) in different biosphere system components may be significantly different from one another and from those corresponding to the lifetimes of members of exposed groups (for which the radiological impacts are typically evaluated). The type of conceptual models suitable for simulating biosphere system dynamics under conditions of change may therefore be very different from those relevant to assessing radiological impact.

## B4.2. PROCEDURE TO DESCRIBE BIOSPHERE SYSTEMS

The procedure that leads to the biosphere system description must provide definitions for the biosphere system components, characteristics and phenomena that may need to be represented in the assessment model.

In practice, a measure of iteration (rather than a simple once-through procedure) will often be necessary in developing a suitable biosphere system description to support long-term radiological assessment. The aim is not so much to derive a complete, detailed description of a hypothetical biosphere system from the "bottom up", but to ensure that the various elements used to support the radiological assessment are broadly coherent. Thus, for example, an initial version of the biosphere system description might be used to support the preliminary development of radionuclide transport and exposure models for a specified assessment context. To the extent that modifications can then be identified to help ensure that the perceived assessment requirements are met, and that available data to support the models are used most effectively, the biosphere system description (and other outputs from the model development process) may need to be further refined.

An iterative approach, based on increasingly refined descriptions of the system, will therefore allow coherence to be maintained while providing a level of detail appropriate to the overall assessment context. The following steps explain in more detail the actions to be followed in arriving at a qualitative and quantitative description of the system of interest.

### B4.2.1. Step 1: Selection of relevant characteristics of identified biosphere system components

In this step the relevant characteristics of the identified biosphere system components (as determined by the 'System Identification' in Section B3) are selected, based on screening of information in Tables Type 'II' from Annex BI. Such screening needs to take into account the underlying assessment context, including the geosphere-biosphere interface and endpoints of the assessment, but could also invoke modelling judgements regarding the likely significance of particular characteristics. It is recognised that there may be situations where it is unclear whether or not particular characteristics are relevant to the biosphere system description, and these will need to be retained for review later in the procedure.

Activities of the identified human community (Section B3) leading to potential radiation exposure (Table HIIb of Annex BI) are also considered in this step. The combination of these potential exposures with additional judgements and knowledge will allow for the definition of potential exposure groups (see Section B5).

In documenting the screening decisions, a record should be kept of which items are considered relevant or not (or 'possibly relevant') to the overall biosphere system description and the reasoning behind the decision. The output of this step will therefore be a record of: (i) those biosphere system characteristics that are considered relevant, or potentially relevant, as a basis for developing a model that meets the overall assessment objective; and (ii) those characteristics that can be justified as not relevant to the scope of the assessment.

### B4.2.2. Step 2: Establish interrelations between biosphere system components

Given the biosphere system characteristics that have been identified as being relevant (or potentially relevant) to the assessment calculation, Step 2 involves establishing the ways in which they are interrelated, thereby providing a phenomenological description of the intrinsic dynamics of the biosphere system. This can be achieved by constructing an interaction matrix (see, for example, (BIOMOVS II, 1996)) to identify important phenomena based on analysis of the interactions (i.e. relationships and dependencies) between the biosphere system components. An example of the use of Interaction Matrices in this way is in analysis of biosphere dynamics underlying the safety performance assessment of the SFR facility at Forsmark in Sweden (Andersson et al., 1998a; 1998b). The *interaction matrix* approach has also been successfully implemented in other areas of repository systems analysis (see, for example, (SKB, 1995)).

The *interaction matrix* approach also provides a clear way of ensuring that each of the identified system characteristics can be 'mapped' into the assessment model. Moreover, the systematic process of examining how the biosphere system components relate to one another may help to identify new, previously unrecognised relevant characteristics of the biosphere system.

#### B4.2.3. Step 3: Basic description of the biosphere system

In Step 3 the information derived through Steps 1 and 2 is used to provide a qualitative description of the biosphere system. This description should include consideration of the characteristics relevant to each biosphere system component and the way in which they are interrelated, both in terms of system dynamics and their assumed spatial arrangement. The result can be considered a 'word picture' of the biosphere system; in practice, a combination of verbal and pictorial description of the biosphere may be helpful, depending on the circumstances of the assessment.

Descriptive parameters are also desirable at this stage in order to provide a more substantive account of (for example) the spatial scale of the particular features that may be identified within the local environment to be represented in the model and the magnitude of the system dynamics. When no site-specific information is available to guide such decisions, other generic information needs to be used. Annex BV provides a guide to typical natural correlations and relationships (both qualitative and quantitative) between biosphere system components and characteristics.

## B5. HYPOTHETICAL EXPOSURE GROUPS

### B5.1. EXPOSURE GROUPS, EXPOSURE PATHWAYS AND CRITICAL GROUPS

This Section describes how information about hypothetical exposure groups is used in developing the Reference Biospheres. Further explanation and details are provided in Annex BII, including possibilities for combining exposure pathways to determine exposure group doses. The need to include any particular level of detail may be influenced by the definition of endpoints provided in the assessment context.

In order to derive a suitable mathematical model for the radiological assessment, there is a requirement to describe and then quantify the ways in which exposures could take place. To do this, it is necessary to describe the key behavioural characteristics (activities) of the exposed populations considered in the assessment, remembering always that these exposures are hypothetical.

To calculate the radiation dose to an exposed individual, the three principal exposure modes (ingestion, inhalation and external) must be linked to potentially contaminated environmental media and other accumulators of radionuclides e.g. flora and fauna.

There are, potentially, a great many activities that could lead to human radiation exposures. What is needed is a systematic way of identifying these activities so that the exposures can be ranked.

Each of the activities represents some aspect of the lifestyle of individuals in the hypothetical exposed population which distinguishes one group of individuals from another. Table HIIb of Annex BI provides a classification of human activities leading to exposure, via interactions with a generic subset of biosphere system components which represent potentially contaminated environmental media. These contaminated media (seven in total) are listed in column 1 of Table HIIb of Annex BI as atmosphere, geological media, soils, sediments, water bodies, fauna and plants. For each application, review of this table enables the modeller to determine the types of exposure-producing activities which may reasonably be considered to take place within the modelled biosphere system. The breakdown by exposure mode for each pathway also helps to determine the ways in which the pathway needs to be described in the model, in terms of the interactions between the exposed individual and the biosphere system components that comprise the contaminated media.

Individuals with similar activities or lifestyles can be grouped into a single hypothetical exposure group. Such exposure groups may be identified from their similar activities (third and fourth columns of Table HIIb).

Many exposure groups could be constructed. Each might represent a particular lifestyle or emphasise a specific set of modelling assumptions. Of particular interest are those groups that produce a high degree of interaction with the potentially contaminated environmental media (the subset of biosphere system components in column 1 of Table HIIb). For some combination of radionuclide concentrations and exposure group activities, the calculated doses will be the highest. The group with these activities is known as the critical group (strictly, the hypothetical critical group).

Annex BII describes two approaches to identifying the critical group in any given assessment context – the *a priori* and *a posteriori* methods. In the *a priori* approach, the assumed characteristics and habits of candidate critical groups are fixed prior to performing the exposure calculation, and the highest resulting dose then serves as a representative indicator of the maximum potential exposure. This has been the basis of a large number of past assessments (see for example, (BIOMOVS II, 1996)). The *a posteriori* approach to identifying exposed groups adopts the premise that it is possible to determine which particular combination of characteristics of human behaviour would cause an individual to be among those incurring a given exposure range (e.g. among the highest exposures) only after each pathway has been assessed quantitatively, having regard to the specific mix of radionuclides present in the discharge to the biosphere at the time of interest.

Neither a strict *a priori*, nor a strict *a posteriori* approach is considered appropriate for assessment purposes. The strict *a priori* approach is deficient because the range of potential exposure pathways accommodated within the biosphere model needs to be sufficiently broad to provide assurance that no substantive issues are ignored. It is appropriate when the context requires it. On the other hand a literal *a posteriori* approach implies that calculations have to be carried out for every potentially exposed individual: an impractical requirement that fails to recognise the importance of expertise and judgement. Some form of intermediate approach is therefore required.

The approach employed here uses Table HIIb of Annex BI to identify groups whose activities would lead to a high degree of interaction with the potentially contaminated environmental media of the biosphere system. These groups are the candidate critical groups for which calculations will be made.

The approach combines exposure pathways in such a way as to reasonably maximise certain activities so that the radiological impact due to those activities is not likely to be underestimated while, at the same time, avoiding unreasonably 'extreme' behaviour. Thus, pathways which are mutually exclusive should not be combined additively, but non-mutually exclusive pathways may be so combined. The flexibility built into the system allows additional combinations of pathways to be identified while providing insight into how other pathways might be subsumed into those that are represented. Account can be taken of preliminary dose calculations to modify the exposure group assumptions as well as other assumptions in the calculation. This iterative method represents the intermediate position between the *a priori* and *a posteriori* approaches.

## B5.2. IDENTIFICATION OF EXPOSURE GROUP CHARACTERISTICS AND MODELLING REQUIREMENTS

Table HIIb of Annex BI indicates the types of data (qualitative as well as quantitative) required to fully describe the exposure groups. Of interest are activities that lead to high levels of interaction with the potentially contaminated environmental media. The key questions are: how much contaminated food does a member of the exposed group consume and how much time does a member of the exposed group spend in proximity to bulk quantities of contaminated materials.

ICRP (as noted in Annex BII) recommends that the Critical Group be representative of those individuals expected to receive among the highest dose within the society identified by the assessment context . ICRP further notes that:

> *"The critical group ... may comprise existing persons, or a future group of persons who will be exposed at a higher level than the general population. When an actual group cannot be defined, a hypothetical group or representative individual should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon present knowledge using cautious, but reasonable, assumptions."*
>
> ((ICRP, 1985) Publication 46, paragraph 46)

This section of the Methodology shows how the BIOMASS approach interprets this basic recommendation of the ICRP. In addition, it is intended that the approach should be flexible enough to allow a wide range of alternative lifestyles to be described and, at the same time, allow radiological protection objectives to be expressed and to be relevant to a wider audience.

## B5.3. CONSUMPTION PATHWAYS

Wherever possible, the consumption database should be based on a survey of activities at the location of interest. If this is not possible (for example, in the case of a non site-specific assessment) or if the assessment is relevant to some future climate state, then data should be taken from an area with characteristics (climate, topography, soil type etc.) as close as possible to that of the assessment biosphere. Ideally, the survey should have been conducted over a large enough sample such that, for example, the 97.5$^{th}$ percentile is reasonably well defined (i.e. survey would have to be for at least a few hundred individuals). There are in existence databases compiled specifically for radiological assessments but these should be used with great care if their survey base does not correspond to the biosphere system to be modelled. In any event, it is recommended that data selection should follow the BIOMASS data protocol provided in Annex BIII.

Several approaches have been employed in the past to assign consumption rate data for radiological assessments and these are discussed in Annex BII. Most often the mean value of survey data has been used for each food type. However, since mean consumption is typical of the general population, this appears to contradict the requirement set out by ICRP (above). Any large population survey (e.g. (USDA, 1998; Bertrand, 1993; Combris et al., 1997)) reveals the very disparate nature of food consumption patterns, reflecting individuals' preferences for particular foods. In the context of the ICRP advice (cautious but reasonable) it is appropriate to allow for this.

While the aim is to reasonably maximise calculated exposure so as to provide confidence that the radiological impact is not underestimated, it is not reasonable to assume that all foodstuffs are consumed at high levels. Such combinations are not seen in real populations (Coomes et al., 1982) where individuals with high intake of foodstuffs generally consume high proportions of only two or three dietary staples.

Recently some databases have appeared which quote not only the mean value of consumption but also provide other details of the statistical properties (e.g. (Robinson, 1996; MAFF, 1997)). There remains the question of how to use these data to define cautious but reasonable exposure groups.

The approach taken here is to use central values from consumption distributions as the baseline for the exposure group definition. Specific groups are then identified which might have increased consumption of the most contaminated foods. Higher consumption levels are then chosen from the upper part of the statistical distribution.

There are different options when it comes to choosing the higher values. (MAFF 1997) cites the "average" consumption rate and an "above average" value, meaning the 97.5$^{th}$ percentile, and in Annex BII it is argued that the 95$^{th}$ or 97.5$^{th}$ percentiles of consumption will generally represent suitable high consumption values for any given exposure pathway.

Where the data are insufficient to provide good statistical information, (Coomes et al., 1982) have shown that it is reasonable to assume that the "higher percentile" may be approximated by three times the mean value. More recent survey data reported in Annex BII support this suggestion. Further consideration is given to this approximation in relation to particular exposure pathways in Part C.

## B5.4. INHALATION AND EXTERNAL EXPOSURE PATHWAYS

In contrast to the representation of consumption pathways, inhalation and external exposure pathways, both of which are related to “occupancy”, have usually been treated in a less detailed way (BIOMOVS II, 1996). Table HIIb of Annex BI indicates that the primary behavioural factor is the amount of time spent (occupancy) at the location at which the exposure arises, though this is not to say that other factors such as breathing rate will not be important. This occupancy parameter links exposures in this category to the activities of the exposure group.

Earlier generations of assessment models avoided this complication by assuming 100% residency in the area of highest contamination If the contamination remains concentrated around a single release point this may be an overly cautious (i.e. not ‘reasonable’) approach. However, if no good occupancy data exist, then it may be convenient to make such an assumption, at least initially. If, after a preliminary quantitative assessment has been conducted, the occupancy assumption leads to the highest contribution to total dose, then this conservative assumption may need to be revisited. This iteration is a key aspect of the BIOMASS Methodology.

Unlike consumption data, relevant occupancy data may be difficult to obtain. Data exist for assessments of present day populations around existing nuclear facilities, e.g. (MAFF, 1997), but here the occupancy figures are for specific contaminated areas and do not take into account time spent elsewhere.

In the BIOMASS Theme 1 examples, human activities are assumed to comprise four types – occupational, recreational, domestic and sleeping activities. Each of these has different characteristics in terms of its location and degree of interaction with the potentially contaminated environmental media. Sleeping takes place in the domestic environment, but the inhalation rate during sleep is less than during waking activity. Occupational activities might take place in any of a number of locations within the modelled system (including areas of contamination in the open air). Some of these might involve increased interaction with the contaminated environmental media. For example, strenuous activities such as ploughing or harvesting might be expected to involve increased inhalation rates combined with increased airborne dust concentrations. It might also be expected that the areas of domestic, recreational and occupational activities would have different environmental concentrations.

In this way the BIOMASS Methodology leads to a description of activities and the occupancy at the various locations of interest. This level of descriptive information about exposure groups’ activities follows the ICRP 81 (ICRP, 1998) recommendation to provide a qualitative description of the potentially exposed groups that is consistent with the modelled biosphere.

## B5.5. COMBINING PATHWAYS TO IDENTIFY CANDIDATE CRITICAL GROUPS

Candidate critical groups are constructed so as to combine consumption, inhalation and external exposure pathways so that, for each candidate critical group, different high exposure activities are brought together in a reasonable way. This is best approached on a case by case basis, taking into account the requirements of the assessment context and the biosphere system description. The approach is summarised in Table B2.

The first two stages provide for a screening of Table HIIb of Annex BI to identify activities that would result in a radiation exposure. Where a mixture of radionuclides is to be considered, consumption will generally lead to higher doses than either inhalation or external exposure. For this reason the candidate critical groups will usually be selected to have high consumption of particular contaminated foodstuffs (e.g. beef, grain etc.). In addition, the groups will be selected to have high levels of occupancy in proximity to the bulk quantities of associated contaminated materials (e.g. bulk quantities of the foodstuff). This is done through the "guidance for Step 3" given in Table B2. This means, for example, that a group with high consumption of, say, green vegetables will also be assumed to be the group engaged in the cultivation of this crop. Two other subgroups could also be identified: consumers of green vegetables who are not involved in production, and producers who do not consume. Clearly, these groups would receive a lower exposure than a group with the combined behaviour. The BIOMASS Methodology also allows for the analysis of other groups to proceed if this is of interest. By the end of the fourth stage of the procedure a fully qualitative description of the exposure groups' activities is available.

At this point there will be sufficient detail to allow suitable databases to be reviewed and selected. This leads on to the identification of "central" and "high" consumption rates. Occupancy values may then be assigned, finally allowing the candidate critical groups to be fully quantified. Iteration to ensure adequacy and consistency is an important feature.

Examples 1, 2A and 2B (Part C) illustrate the practical application of the BIOMASS Methodology.

TABLE B2. SEVEN STEP PROCEDURE FOR THE IDENTIFICATION AND CHARACTERISATION OF CANDIDATE CRITICAL GROUPS

| | |
|---|---|
| 1. | Review exposure modes, exposure pathways and examples of typical activities that might lead to exposure. Link the conceptual model objects (the potentially contaminated environmental media, as explained in the next chapter) to exposure via examples of exposure pathways. |
| 2. | Identify relevant activities in the modelled biosphere system, organising the activities according to exposure mode. |
| 3. | Identify candidate critical groups by combining activities based on consumption rates and occupancy values for inhalation and external exposure, linking activities to locations within the model region. |
| **Guidance for Step 3:** | |
| Rule 1 | It is appropriate to consider *central* consumption rates with a small number of *higher* consumption rates when identifying exposure groups' activities as determined by foodstuff consumption. Depending on the source of data on which the consumption rates are based (correspondence of survey data to the modelled biosphere system, quality of data etc.) *central* values can be mean or median value, and *higher* values can correspond to some high percentile (95$^{th}$ or 97.5$^{th}$) or can be approximated as three times the mean. |
| Rule 2 | The choice of *higher* consumption rates should be linked to activity and location. Perspective can be provided by assessing the dose to the exposure group based on all central consumption rates. |
| Rule 3 | Look for activities which place individuals in the location of the conceptual model objects (the potentially contaminated environmental media). |
| Rule 4 | Maximise the amount of time spent in contaminated regions, while allowing for activities elsewhere. As a first approximation divide time into occupational, recreational, domestic and sleeping. |
| Rule 5 | Where possible aggregate patterns of behaviour into the same group. |
| 4. | Construct a qualitative description of the activities of the candidate critical groups and review to merge groups if possible. |
| 5. | Assign numerical consumption rates. |
| 6. | Assign occupancy values for locations near to crops, livestock, and other food resources. |
| 7. | Fully characterise the candidate critical groups detailing consumption rates and occupancy values. |

## B6. MODELLING AND DATA

### B6.1. INTRODUCTION

Model development in the BIOMASS Methodology builds on work done in BIOMOVS (1993) and BIOMOVS II (1996a and 1996b). In these earlier projects good modelling practice was identified by bringing together practitioners from many countries and organisations.

BIOMASS used this experience to develop a methodology that would allow biosphere assessment models to be developed in way that was both practical and transparent. Model development therefore follows a systematic approach that allows assumptions and any appropriate simplifications to be recorded in a traceable fashion. The starting point for simulating radionuclide transport and accumulation is a description of the biosphere system (including the human community) in which exposures are assumed to take place, coupled with a description of the assumed geosphere-biosphere interfaces for radionuclide release into the system.

The development and justification of an assessment model will not always be a linear process; an iterative approach to refining the model, coupled to enhancement of the corresponding biosphere system description, may be necessary to ensure that a practicable and justifiable approach is achieved. Nevertheless, the following basic steps can be identified:

(1) identify those biosphere system components that are to be characterised as separate conceptual model objects (i.e. distinct potentially contaminated environmental media) in the representation of radionuclide transport;

(2) taking account of the assumed spatial configuration and intrinsic dynamics of the biosphere system components, devise a conceptual model of radionuclide transport between these media;

(3) ensure that all relevant FEPs are adequately addressed within this representation of contaminant behaviour in the system, taking account of the phenomena identified in the biosphere system description;

(4) define the mathematical model, taking account of available data sources and scientific understanding related to the phenomena of interest.

## B6.2. IDENTIFICATION OF CONCEPTUAL MODEL

Environmental media to be represented as separate conceptual model objects should be distinguished not only on the basis of their potential contribution to radiological impact (e.g. resources used by exposure groups), but also in terms of the role they would play in the migration and accumulation of radionuclides (see Table HIIb, Annex BI). Thus:

— **Climate** relates to certain boundary conditions imposed on the local biosphere system that need to be represented within the model. It does not therefore correspond directly to a physical medium in its own right. In practice, however, consideration of climate serves as a prompt to consider whether atmosphere needs to be explicitly represented as a separate environmental medium, or conceptual model object. In situations where solid material or groundwater transport is the release mechanism at the geosphere-biosphere interface, potential exposures to radionuclides in the atmosphere can usually be derived directly from the estimated contamination of other environmental media. Explicit representation of the atmosphere within an assessment model will therefore generally be necessary only where the biosphere system is defined such that migration though the atmosphere needs to be considered in terms of its role in radionuclide transport. Nevertheless, from the perspective of communicating understanding of contributions to potential radiation exposure pathways, it may be informative to include atmosphere as an integral part of the conceptual model.

— **Water Bodies** relate to two main classes of environmental media within the conceptual model: surface waters and subsurface waters. Each surface water body – whether natural or artificial – that is identified as belonging to the domain of the biosphere system of interest can play a distinct role in the distribution of radionuclides, and may support a separate ecosystem or subsystem. Individual surface water bodies (e.g. stream, lake etc) will therefore usually need to be separately identified within the conceptual model for radionuclide transport. Subsurface water bodies identified as belonging to the biosphere system are translated into the model by combining them with the assumed water-bearing parts of the near-surface geology (see below); thus, for example, regional saturated zone and sedimentary geological formation defines an aquifer. Depending on how potential transport and exposure pathways are affected by the assumed spatial and temporal characteristics of water bodies, as well as their configuration within the biosphere system, it may be helpful to identify different parts of a water body as separate conceptual model objects. For example, it may be convenient to distinguish between deep and shallow lake waters, or permanently and intermittently saturated regions of an aquifer.

— The fundamental role played by the **Human Community** as a principal component of the biosphere is an important part of the system description, but will not necessarily be directly relevant to the conceptual representation of radionuclide transport. Indeed, assumptions relating to the contribution of the community to potential contaminant migration and accumulation pathways will normally be implicitly incorporated in the descriptions of the characteristics, configuration and dynamics of other biosphere system principal components. Nevertheless, it can guide understanding (and modelling) of migration pathways in the system to recognise that, for example, consumption of contaminated produce and disposal of waste products by members of exposure groups may be a vector for radionuclide transfer either within or outside the domain of the biosphere system. Moreover, consideration of the human community as a principal component of the system serves as a prompt to recognise that models for radiation exposure will typically be required in order to determine the required assessment endpoints.

— **Biota** are classified as separate principal components within the system identification primarily in terms of the types of ecosystem that are assumed to be present within the biosphere. The more detailed description of the biosphere system is then developed in two stages (see Section B4). First, each ecosystem is described in terms of its mix of plant (native/cultivated) and animal (native/domesticated) communities. The characteristics of these communities are then described as necessary, according to the demands of the assessment context. From the perspective of resource exploitation by potential exposure groups, an appropriate level of disaggregation for the purposes of conceptual model development would be to distinguish between native and cultivated/domesticated plants or animals within each identified terrestrial or aquatic ecosystem of interest. A different disaggregation would probably be required if the assessment focus were other than the radiological impact on man.

— **Geology** helps to define the configuration of the hydrogeological system and – in so far as subsurface waters are deemed an important principal component of the biosphere system of interest to the assessment – can therefore be relevant to distinguishing specific conceptual model objects (see above). However, the description of aquifer characteristics will already implicitly incorporate much of the relevant geological information.

— **Soils/Sediments** are intrinsic principal components of terrestrial and aquatic ecosystems and it is therefore appropriate to identify physically distinct regions within the conceptual model, linked to each ecosystem that is identified as being present within the biosphere. Depending on assumptions concerning the nature of the geosphere-biosphere interface and on how principal components of the biosphere system are spatially configured, further sub-division may be required to distinguish regions of the same soil or sediment type that play distinctly different roles in radionuclide transport and migration within the biosphere. For example, if the interface for release to the biosphere is an irrigation well, it may be appropriate simply to consider a single "irrigated soil" medium. Alternatively, for contamination resulting from natural discharge of groundwater, there may be several different soil/sediment types and regions of interest.

— **Topography** relates to the overall description of the structure of the biosphere system and, thereby, to the potential significance of certain phenomena – particularly bulk material flows. It is therefore relevant to the modelling of transfer pathways and FEPs, but does not need to be specifically represented in the conceptual model (see Section B1).

### B6.3. CONCEPTUAL REPRESENTATION OF RADIONUCLIDE TRANSPORT PATHWAYS

Based on such an analysis of the biosphere system, a conceptualised description of the dynamics of contaminant transport through the biosphere is then developed. This could be achieved in a variety of ways. Within BIOMASS, an interaction matrix diagram has been useful in providing a condensed representation of transfer pathways. This application of the interaction matrix is acknowledged to be different from its earlier use, as part of the procedure for biosphere system description (see Figure B5), where it provided a comprehensive basis for identifying phenomena responsible for the influences of one biosphere system component on another. However, one advantage of adopting a similar method of presentation to that used in developing the system description is that it is easier to trace an audit trail demonstrating how relevant biosphere system phenomena are ultimately represented as FEPs in the conceptual model for radionuclide transport.

A simple example of the first stage in developing a matrix representation of the conceptual model is illustrated in Figure B6. The leading diagonal elements (LDEs) of the matrix correspond to the various media that have been identified as being relevant conceptual model objects in the representation of contaminant migration within the hypothetical biosphere system and in the evaluation of radiological impact. In practice, the number of leading diagonal elements used to represent the conceptual model will depend on the required complexity of the biosphere system and the geosphere-biosphere interface. For the example presented here, it is assumed that the biosphere system consists only of farm land irrigated by water from a local river. Potential transfer pathways associated with river ecosystems are assumed to be excluded.

The concept of the geosphere-biosphere interface is introduced within the interaction matrix through an additional leading diagonal element (*Source Term*) representing the release of radionuclides to any part of the biosphere system. Interface issues can then be addressed as interactions between the Source Term and other LDEs. An additional final leading diagonal element (*Sink*) is also included to represent the loss (whether by radioactive decay or migration) of radionuclides from the domain of the biosphere system of interest.

The conceptual representation of the biosphere system is then completed by identifying all FEPs that are associated with contaminant transport between those environmental media that have been represented as separate conceptual model objects. Off-diagonal elements (ODEs) of the matrix therefore correspond to FEPs associated with radionuclide migration and accumulation in environmental media. Radionuclide transport pathways will depend on the assumed configuration of the biosphere system components, as outlined in the system description.

During completion of the matrix representing the conceptual model for contaminant transport, it is important to bear in mind that more than one FEP can appear in any given matrix element and that any particular FEP can, as appropriate, appear in more than one element. LDEs would normally be assumed to represent 'Features'; however, it is also quite possible for them to incorporate 'Events and Processes'. For example, a matrix LDE representing a surface water body might be defined such that it implicitly incorporated the advection, dispersion and settling of contaminated materials within the water column. If it were considered that more detailed conceptual representation of events and processes intrinsic to a specific LDE was necessary as a basis for selection of a suitable mathematical model, this could be explored at a greater level of detail by expanding the interaction matrix to incorporate additional LDEs. The further disaggregation of the biosphere system in this way, to ensure that a suitable model structure is adopted, is an example of the iterative approach referred to above for refining the model and biosphere system description.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Source Term | | | | | | | |
| | Atmos-phere | | | | | | |
| | | River | | | | | |
| | | | Irrigated Soil | | | | |
| | | | | Crops | | | |
| | | | | | Domestic Animals | | |
| | | | | | | Exposure Group(s) | |
| | | | | | | | Sink |

*FIG. B6. Example Interaction Matrix Representation of Conceptual Model for Radionuclide Transport in a Simple Biosphere System.*

## B6.4. CONCEPTUAL REPRESENTATION OF EXPOSURE PATHWAYS

In order to complete the conceptual model for radiological assessment, exposure pathways need to be identified and associated with each of the environmental media represented in the conceptual model for radionuclide transport. Basic assumptions relating to the exploitation of biosphere resources by the human community are fundamental to the definition and description of the biosphere system components (including their extent). Therefore, the LDEs in the interaction matrix of Figure B6 already take into account underlying assumptions relating to potential sources of radiation exposure in the biosphere system, although not necessarily the specific exposure pathways that may be associated with the habits of potentially exposed groups.

A checklist of exposure modes and pathways associated with activities that might be undertaken by members of the human community is included as one of the tables of biosphere system characteristics (Table HIIb) presented in Annex BI. As with other system characteristics, the systematic selection of exposure pathways as part of the overall conceptual model for radiological assessment is undertaken by screening the entries in Table HIIb, taking into account the underlying assessment context and including, where appropriate, modelling judgements regarding the relative significance of particular pathways.

## B6.5. CONCEPTUAL MODEL REFINEMENT AND AUDIT

A series of iterations of the conceptual model development process might be undertaken if time and resources allow. Following such an approach, all possible FEPs representing interactions between the LDEs in the interaction matrix would be considered in the first iteration; subsequent iterations would then refine the analysis until finally only those that will be explicitly represented in the mathematical model remain. Practically, it should also be recognised that new FEPs might be introduced for consideration at any time within an assessment. An iterative approach provides a framework for introducing these new FEPs into the conceptual model. One consideration in refining the conceptual model is that, subject to the overall requirement that it should satisfy the purposes determined by the assessment context, the model should generally also be as simple as possible. Additional complexity that does not lead to a meaningfully improved estimate of the required assessment endpoints should be screened out. The iterative process therefore helps to focus attention on the development of robust arguments and justification for the screening of FEPs. Alternatively, evidence from scoping calculations or previous assessments may enable such decisions to be made at an early stage, allowing completion of the conceptual model building process in a single iteration.

In order to provide a coherent justification for FEP screening decisions in the conceptual model, it is important to be able to trace the relationship between the conceptual model for radionuclide transport and the underlying biosphere system description. In developing a systematic audit trail, it is helpful to provide a record showing how all phenomena that were identified as ‘relevant’ within the biosphere system description have been addressed in the treatment of FEPs in the conceptual model for radionuclide transport. This record should indicate:

— those phenomena that have been represented in the conceptual model, with their corresponding location as FEPs within the interaction matrix;

- those phenomena that were screened out from consideration during development of the interaction matrix, with reasons for their omission;
- those FEPs that correspond to additional phenomena that have been introduced as a result of development of the interaction matrix.

Finally, in order to demonstrate comprehensive coverage of potentially relevant FEPs, it can be helpful to undertake an audit of both the biosphere system description and conceptual model against an independent FEP list to confirm that no potentially significant FEPs were omitted from consideration. Systematic review against an independent source provides a final opportunity to check the completeness of the screening arguments used in developing the biosphere system description and conceptual model. In particular, it helps to ensure that:

- FEPs have not been mistakenly screened in/out during the development of the biosphere system description or conceptual model;
- the identification of all relevant FEPs is complete and that they have been accounted for in the records of the model development process.

Annex BIV presents a generic FEP list for biosphere assessment, based on that originally developed in BIOMOVS II (1996a).

### B6.6. MATHEMATICAL MODEL DEVELOPMENT

Much of the process of mathematical model development and (where appropriate) software implementation is not specific to biosphere assessment. An effective audit trail can typically be developed through generic Quality Assurance systems, which are not limited to biosphere modelling. Nevertheless, the following points (originally identified in BIOMOVS II (1996a)) are relevant.

The development of a mathematical specification involves consideration of two primary factors:

- the mathematical operations that process the information contained in identified model parameters;
- the sources and routes of information transfer into, and out of, the model.

Mathematical representation of a conceptual model depends on a proper understanding of the importance of FEPs to radiological assessment and the ways in which they can best be interpreted mathematically, given available scientific information. Modelling constraints, such as the preferred solution method for the model, or the availability of data, may restrict the ability to represent particular effects or processes, and thereby reduce the number of FEPs from the conceptual model that can be included explicitly. Moreover, the process of reviewing data sources and references to identify or select suitable parameter values for the model may result in modifications to the model, albeit at the level of fine detail. Separate models may need to be developed if all important FEPs cannot easily be combined in a single mathematical representation.

During the course of developing the mathematical model, or models, a list of parameters relevant to the calculation will be identified. Each of these, and their specific meaning within the context of the model, should be documented to provide a clear basis for establishing the necessary databases. In practice, the mathematical representation of many processes tends not to be explicit, but is instead based on an empirical model of effects observed at the system level. For example, the uptake of radionuclides by plants and other biota is often represented in terms of a bioaccumulation factor. An empirical model of this type can represent the combined action of several FEPs (e.g. root uptake and translocation) identified separately within the interaction matrix. Where this is the case, care needs to be taken in order to avoid double-counting the effects of certain processes or, conversely, the inadvertent exclusion of potentially relevant FEPs.

The development of a suitable audit trail is a fundamental element of each stage of the model development process. This enables lessons learned in applying the model and interpreting its results to be used to revisit assumptions and decisions. Such information may also be used to refine the model, perhaps by identifying particularly important FEPs or sensitive parameters. A systematic methodology thus provides a 'living' approach for incorporating new information into biosphere assessments, taking account of experience from using the models, changing assessment contexts, new scientific understanding and evolving regulatory requirements.

## B6.7. APPLICATION OF DATA TO ASSESSMENT MODELS

The process of software design, based on a given mathematical specification, involves consideration of appropriate solution algorithms, data and process structures. Software design should be conducted within an appropriate software development Quality Assurance system. However, one key element of the software design process that is not typically well controlled by such formal procedures is the way in which parametric data bases are set up and used within the model. A systematic approach to the choice and use of data appropriate to biosphere assessments was developed within BIOMASS. It is recognised, however, that the full implementation of such an approach may have significant resource implications. A balance therefore needs to be struck taking into account the perceived sensitivity of the assessment results to uncertainties in model parameters, and the implications of such sensitivities for the conclusions that will be drawn from the results.

The construction of databases for models and the interpretation of data, including the definition of uncertainty bounds on parameter values, have been shown through intercomparison exercises such as BIOMOVS II to be particularly important factors contributing to differences in model results and interpretations. The derivation of assessment-specific parameters from a wider data base of basic biosphere information is a general problem in environmental modelling. In long-term biosphere assessments the difficulties are compounded by the need to represent both the existing biosphere system (where this is known) and possible future systems.

No general guidance on such problems was developed during BIOMOVS II, although some specific questions were identified as needing further consideration. It was therefore proposed that a set of guiding principles should be developed within BIOMASS, as an element of the BIOMASS Methodology to be applied to long-term biosphere assessments.

Past experience has demonstrated that there is an extensive list of issues, or at least constraints, associated with the overall management of data:

— the strong relationship between models and data: each aspect influences the other, and they should be considered in parallel when developing models and determining parameter values;

- data are categorised: they belong to main families which are different, thus data should be treated differently when gathered and processed according to their data type;
- there are various sources of data coming from different scientific disciplines and these sources have often been produced for various purposes;
- consequently, the available data may or may not be suitable for a given assessment context, and one should react accordingly;
- the selection and representation of data in order to determine a parameter value is not straightforward, even if data are available;
- there are numerous sources of uncertainty affecting the production of data and the determination of parameter values.

Nonetheless, awareness of these issues has existed since the beginning of the development of assessment models, and different approaches have been used for controlling them:

- the direct recourse to expert judgement, sometimes searching for a certain level of consensus, but without following a formal elicitation process;
- the identification of the most important parameters and the appraisal of the consequence of the uncertainty in their determination through the performance of sensitivity and uncertainty analyses after undertaking assessment calculations;
- the performance of elicitation exercises combining qualitative and quantitative arguments organised through structured approaches prior to undertaking assessment calculations.

However, when focusing on the biosphere element of a waste disposal safety assessment, one usually faces the problem that the biosphere aspect has not been addressed in a comprehensive way. Often, there is only partial information in the literature, in the sense that some specific factors, such as the variability of the data types and the heterogeneity in data availability, may be missing.

Because of the difficulties associated with the management of data, whether it is the production and control of their uncertainties, or the selection of parameter values along with the development of models, it is not possible to consider this issue as a mere sequential step in the safety assessment procedures. Rather, all the topics that are associated with the application of data to assessment models lie at the cross-roads of several technical fields and, in the particular area of biosphere modelling, they also depend on interactions with other parts of the BIOMASS Methodology such as modelling.

For these reasons, data management should be considered from the beginning of any safety assessment exercise, especially due to the influence it can have on modelling developments and because it can be resource consuming. Its treatment should be explicit and properly documented, trying to avoid confusion and potential loss of information. Data management should interact strongly with other parts of the BIOMASS Methodology as one element of an integrated process that depends on various assumptions (especially from the safety assessment context) and that can influence in return these other parts (e.g. owing to the data availability). Consequently, the treatment of data should certainly involve discussions with people who have different backgrounds, in order to avoid bias and to try to benefit from synergies.

The construction and implementation of a protocol for the derivation of data are important to demonstrate rigour in the overall data management. The main steps composing such a protocol have been identified (Annex BIII) as:

(1) an introduction, as a way to take into account the assessment context and other external constraints, and to list the easily available information;

(2) the structuring of information, so as to define properly the quantities under scrutiny and to review the scientific and technical aspects which can govern their determination;

(3) conditioning, which is a step where qualitative decisions are taken in order to adapt the previous knowledge to specific studies;

(4) encoding, which is the step where quantitative decisions are expressed, leading to data determination in its strict sense;

(5) adoption of a formal output format, essential for enabling traceability and communication.

The protocol for derivation of data demonstrates the advantages embodied in any structured approach: it should be documented, leading to its understanding even by people who would not have been directly involved in its implementation; it should be traceable, allowing the performance of multiple iterations when updates are required; and it should be defensible. Last but not least, the data protocol has proved applicable and adaptable to the biosphere realm as demonstrated by its application to illustrative examples such as the determination of an ingestion dose factor from a prescribed source, and the determination of a soil $K_d$ and a soil-to-plant transfer factor from the scientific literature and/or expertise (Annex BIII).

The multiple steps that comprise the data protocol should not be perceived as a burden preventing the adoption of common simplifications that have been developed through experience. The protocol can be greatly simplified when regulations clearly impose data choices, when there is a consensus for justifying simplicity, when a certain level of technical arbitrariness is adopted (e.g. through the modelling of highly stylised situations), or when some parameters are known to be less important (through sensitivity analyses). The requirement remains to document such decisions and the rationales which support them.

Figure B7 illustrates the relationships between data types, data availability and data requirements in a structured approach to data management. The top part of Figure B7 shows that data management begins after some other parts of BIOMASS Methodology have been completed (i.e. data requirements become apparent from the assessment context, the description of the biosphere system with its critical, or other potential exposure group(s), and information on the models to be used). Some of these activities may occur in parallel (e.g. database/mathematical models). Sometimes mathematical models drive data requirements and sometimes mathematical models are driven by data availability. One seldom starts from scratch and there is a need to manage various types of data, from prescribed databases to special data interpreted from experiments, through to other types of existing data that are more or less well-accepted.

The data protocol (Annex BIII) focuses on the four branches (I to IV) between "evaluation of available information" and "performance of assessment". The most difficult part of data management is branch (IV) (i.e. where there are few or poorly characterised or no data) and this justifies the implementation of a formal elicitation procedure. The rationale for the data classification method is availability and homogeneity in terms of sources (or references). The data protocol applied to branch (I), i.e. for prescribed data found in international databases, will certainly be extremely simplified (identification of data required and mere extraction of the most relevant values). For proper documentation (traceability), the protocol is nonetheless of interest for branch (I). Hence, even if prescribed data are considered, the data protocol aims at demonstrating that selection of data is made in an explicit way. This is also the case for branch (II) for which data come from widely accepted databases or other kinds of well characterised data. Branch (II) data also show a good fit between the assessment context and the available well characterised data; the loop after "update of methodology" can help with enhancing such databases.

Branch (III) data could be compiled by the implementation of the data protocol by one person from the assessment team since the data are not considered to be key for the assessment. The database created through branch (III) should be considered at a lower level than I and II (because it is assessment specific). The treatment of branch (IV) data is more dependent on basic scientific literature concerning experiments and, because the data are key for the assessment, it is recommended that selection should be accomplished through expert elicitation and implementation of the full data protocol.

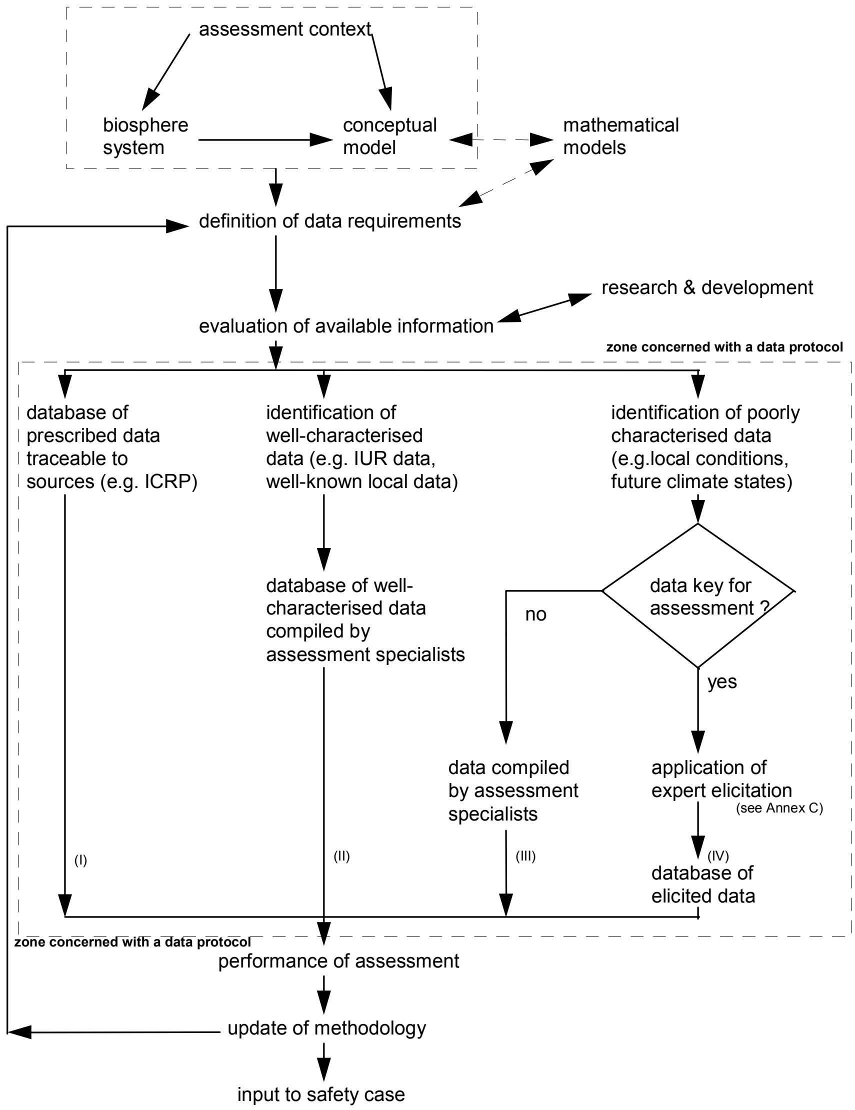


*FIG. B7. Relationships between data types, data availability and data requirements for structured data management.*

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## ANNEX BI
## DEFINITION AND GENERIC CLASSIFICATION SCHEMES FOR BIOSPHERE SYSTEM COMPONENTS

This annex sets out Type I Tables of biosphere system components (principal components and principal component types), and Type II Tables which define the characteristics of the these components. These tables are offered as part of the BIOMASS Methodology. However variants of these tables could be employed without altering the methodological approach.

### BI–1. TYPE I TABLES OF BIOSPHERE SYSTEM COMPONENTS

#### BI–1.1. CLIMATE AND ATMOSPHERE

Climate is determined by planetary air currents in the atmosphere. Although the atmosphere is a basic physical component of the biosphere system, where relevant transport processes or meteorological conditions can take place, its description is usually assumed jointly with the description of local climate.

At a global scale, meteorologists distinguish seven climate belts (Walter, 1984): (1) the equatorial rain zone, (2) the summer-rain zone on the margins of the tropics, (3) the subtropical dry regions, (4) the subtropical winter-rain regions, (5) the temperate zone with year-round precipitation, (6) the subpolar zone, and (7) the polar zone. These climate belts are related to ecosystem types by providing for a further subdivision of the temperate zone, and combining the subpolar and polar zones. Nine climate zones are then be identified, ecologically designated as zonobiomes[2] (ZB):

ZB I: Equatorial with diurnal climate, humid
ZB II: Tropical with summer rains, humid-arid,
ZB III: Subtropical-arid (desert climate), arid,
ZB IV: Winter rain and summer drought, arid-humid,
ZB V: Warm-temperate (maritime), humid,
ZB VI: Typical temperate with a short period of frost (nemoral),
ZB VII: Arid-temperate with a cold winter (continental),
ZB VIII: Cold-temperate (boreal),
ZB IX: Arctic (including Antarctic), polar.

There are other possible climatological classifications, such as the empirical scheme based on average temperature and precipitation values, developed by Köppen (Strahler, 1984). Table CI provides a summary description of the climate associated with the nine zonobiomes, comparing these with the Köppen classification scheme.

[2] A biome is a large and climatically uniform environment within the biosphere.

## TABLE CI. CLIMATE TYPE CLASSIFICATION

| Walter | Köppen | Description |
|---|---|---|
| **ZB I**: Equatorial with diurnal climate, humid | **Af**: tropical climate | The mean monthly temperature is close to 26ºC in every month, so the annual variation is very small. The atmospheric mean pressure ranges from 74.5 to 74.7 cm (1009 to 1012 mb). This is a zone of very intensive precipitation, over 200 cm/y in most of the areas (Strahler, 1984). |
| **ZB II**: Tropical with summer rains, humid-arid | **Am**: tropical climate, monzonic<br>**Aw**: tropical climate, savanna | **Aw** is a humid-arid tropical climate, with a humid season that is determined by maritime humid tropical and equatorial masses of air and in the period that the sun is low.<br>The limit between **Am** and **Aw** varies according to the total annual precipitation of both the wettest and the driest month.<br>The rain in these climates is not so reliable as in humid equatorial. The alternation of the humid and dry seasons causes the development of a typical vegetation, the tropical savanna. This is characterised by open areas covered by grass, with few trees and shrubs that resist the dryness (Strahler, 1984). |
| **ZB III**: Subtropical-arid (desert climate), arid | **BWh**: desert climate<br>**BSh**: steppe climate | A subtropical zone is in general termed desert when the annual rainfall is less than 200 mm and the potential evaporation more than 2000 mm (up to 5000 mm in the central Sahara). A very distinctive feature of all arid regions is the large variability in amount of rain falling in different years. This means that average figures are of little value. In all deserts (except in the fog variety), the air is very dry. Both incoming and outgoing radiation are extremely intense, which means that the daily temperature fluctuations are large. In the rainy season, however, the extremes are greatly reduced (Walter, 1984). |
| **ZB IV**: Winter rain and summer drought, arid-humid | **Csa Csb**: Mediterranean climate | Characterised by dry, hot summers with humid, mild winters. |
| **ZB V**: Warm-temperate (maritime), humid | **Cfa**: humid subtropical climate | A transitional zone between the tropical-subtropical and the typical temperate regions. In the very humid subzonobioma (with rainfall at all times of year but at a minimum in the cool season), temperatures drop quite severely in the cool season, and there may even be frost, but there is no cold season. A second subzone with rainfall occurring principally in winter and no summer-drought season can be distinguished (Walter, 1984). |
| **ZB VI**: Typical temperate with a short period of frost (nemoral) | **Cfb**: warm rainy climate, warm summer<br>**Cfc**: the same, but short and fresh summer | A temperate climate zone with a marked but not too prolonged cold season occurs only in the Northern Hemisphere; apart from certain mountainous districts in the southern Andes and in New Zealand. Warm vegetational season of 4-6 months with adequate rainfall and a mild winter lasting 3-4 months (Walter, 1984). |
| **ZB VII**: Arid-temperate with a cold winter (continental) | **BWk - BWk`**: fresh to cold desert climate<br>**BSk - BSk`**: steppe fresh to cold climate | The degree of aridity varies considerably, and four subzonobiomes can be distinguished: (1) semi-arid having a short period of drought, with steppe and prairie vegetation; (2) a very arid subzonobiome, with as little rain (falling in winter) as the subtropical desert climate; (3) a subzonobiome similar to 2, but with summer rain; and (4) deserts of the cold mountainous deserts plateaus (Walter, 1984). |
| **ZB VIII**: Cold-temperate (boreal) | **Df Dwc Dwd**: forest climate, cold and snowy | The duration of the period with a daily average temperature of more than 10ºC drops below 120 days and the cold season lasts longer than 6 months. The northern boundary between the boreal zone and the arctic tundra is where only approximately 30 days with a daily mean temperature above 10ºC and a cold season of 8 months are typical. A distinction should be made between a cold oceanic climate with a relatively small temperature amplitude and a cold continental climate in which, in extreme cases, a yearly temperature span of 100ºC can be registered (from a maximum average monthly temperature of +30ºC to a minimum of -70ºC) (Walter, 1984). |
| **ZB IX**: Arctic (including Antarctic), polar | **ET**: tundra climate<br>**EF**: polar climate, perpetual frost | The largest tundra region completely devoid of forest is an area of 3 million $km^2$ in northern Siberia. At most, there are 188 days in the year with mean temperature above 0ºC, and sometimes as few as 55. The low summer temperatures are partially due to the large amount of heat required to melt the snow and thaw out the ground. Winters are rather mild in the oceanic regions but extremely cold in the continental regions. Precipitation is slight, often being less than 200 mm, but since potential evaporation is also very low, the climate is humid. Surplus water is unable to seep into the ground because of the permafrost and thus extensive swamps are formed. Snowfall amounts to 19-50 cm annually. |

## BI–1.2. NEAR-SURFACE LITHOSTRATIGRAPHY

### BI–1.2.1. Geology

Parent rock and its genesis influence the shape, size and development of erosional relief. A rock classification scheme based on origin is provided in Table GI, under the basic headings of Igneous, Sedimentary and Metamorphic. This allows the general type of rock present at a particular location to be identified.

TABLE GI. CLASSIFICATION OF ROCK TYPES (STRAHLER, 1984)

| Rock Type | Description |
|---|---|
| IGNEOUS | Rocks that have solidified from a molten state. There are two primary types: **Plutonic** (rock from magma rising up from deep under the earth's crust, and solidifies as it cools before it reaches the earth's surface, e.g. Granite, Peridotite) and; **Volcanic** (rock that was originally lava, hot magma that reached the surface of the earth before it hardened, e.g. Obsidian, Basalt, Rhyolite) |
| SEDIMENTARY | Rock formed by the accumulation of particles on or near the earth's surface, and compacted down, often under extreme pressure, creating rock layers. E.g. Limestone, Gypsum, Sandstone, Dolomite, Quartzite. |
| METAMORPHIC | Rocks resulting from changes within pre-existing rocks, by extreme pressure, temperature, and chemical activity e.g. Mica, Calcite, Gneiss, Quartz |

### BI–1.2.2. Edaphology (soils and sediments)

Climate, topography, parent rock and vegetation together determine whether or not a soil layer is developed and, if so, its specific properties. Soils are formed from a mixture of mineral substances (produced as a result of the weathering of rocks) and organic matter (the product of the activities of organisms and of the decomposition of dead organic matter, mostly plants).

Soils often consist of several layers that may differ in colour and composition. The upper layer (the A-horizon) contains the decomposition products of organic matter as well as mineral matter. The next layer (the B-horizon) includes mostly mineral components. Soluble inorganic material is carried from A horizon to B horizon by the downward flow of soil water. The third layer (the C-horizon) consists of slightly altered debris of the original rock (also known as unconsolidated rock).

Many different soil classifications can be found in the literature, to the extent that many countries have their own classification scheme based on slightly different properties/purposes. Since the 1970s there has been an international effort promoted by FAO–UNESCO to avoid confusion by developing a general classification that can be referenced world-wide.

A zonal soil classification is used here for consistency with the climate zones defined in Table CI (Table RT2 shows the Climate-Soil-Vegetation interrelationships). Table SI provides a summary classification of different soil types that may be present in the biosphere system, including a brief description and comments regarding their natural fertility or other properties. Correspondence with the FAO–UNESCO classification is also indicated.

## TABLE SI. ZONAL SOIL TYPES AND DESCRIPTIONS (STRAHLER, 1984)

| Soil type | Description | Comments |
|---|---|---|
| Equatorial brown clays (ferralitic soils, latosols) | **Latosols**: chemical and mechanical decomposition of the parent rock is complete due to the temperature and humidity conditions. Silica has disappeared almost completely, humus is scarce due to the quick bacterial activity, soils are typically red. The loss of clay-silica minerals make the latosols slightly plastic and notably porous. | Latosols loose fertility quickly after the first few harvests. They can form strata where deposits of great value can be found (aluminium oxide, iron oxide or manganese oxide).<br>*FAO nominat.: e.g: Ferralsols* |
| Red clays or red earths (savanna soils) | **Red soils**: Areas of this type of soils have in common a notable degree of climatic dryness (winter or summer season). This causes the presence of calcium carbonate in the lower layers. The red colour is the evidence of the presence of iron oxides where there are limited quantities of organic acids. | *FAO nomination: e.g. Vertic Cambisol, Chromic Luvisols and Vertisols.* |
| Sierozems | **Sierozems**: they are poor in humus due to the disperse distribution of vegetation. Colour goes from light grey to brown-grey. The horizons exist but only slight differences are found. Big quantities of calcic carbonate at depth less than 0.3 m. | Soils are appropriate for cultivation only where the soil texture is fine, for example along the flooding plains. Irrigation is essential.<br>*FAO nomination: Xerosols* |
| Mediterranean brown earths | **Brown earths**: the soil profile is similar to the chernozem one but with less humus content. | These soils are fertile in adequate conditions of precipitation or irrigation.<br>*FAO nomination: e.g. Cromic Cambisols and Luvisols* |
| Yellow or red podzol soils | **Yellow-red podzols**: Warm summers and soft winters favour bacterial action. Humus content is low. Red and yellow colours are due to iron compounds in hydroxide form. Aluminium hydroxides are also plentiful, caracteristic of tropical soils in warm and humid regions. | *FAO nomination:* e.g. Orthic *acrisol* |
| Forest brown-grey soils | **Brown-grey podzols**: the leaching is less intense than in yellow-red podzols and the colour is brown. The B-horizon is thick and brown-yellow to brown-red colour and, as in podzols, there is a concentration of bases and colloids. | These soils treated with lime and fertilizers allow for highly productive farms.<br>*FAO nomination: e.g. ferric or albic Luvisols* |
| Chernozems | **Chernozem or black earths**: profile typically consists of two layers: just under the vegetal cover there is a black layer (A horizon) rich in humus and of about 0.6-0.9 m thick. C horizon accumulates colloids and bases from A horizon. They are rich in calcium. This soil type is developed over parent material rich in calcium carbonate. Aridity is another important factor in the development of this soil. | Steppe pasture and meadow are the natural vegetation of this soil in medium latitudes. Geographically, the most important property of chernozems is the productivity of cereals (wheat, oats, barley and rye).<br>*FAO nomination: Chernozems* |
| Podzols (raw humus-bleached earths) | **Podzols** require a cold winter and an adequate precipitation range distributed throughout the year. A horizon is formed by three layers where the first stratum is rich in dead or in decomposing vegetation, under this an acid stratum rich in humus can be found, under this a highly leached stratum exists. B horizon has a heavy clay consistency due to the colloids coming from A horizon. Both A and B horizons are less than 1 m thick. | Fertility is limited, which make the soils not appropriate for cultivation, although the addition of lime and fertilisers corrects its acidity and restores the leached bases to the soil.<br>*FAO nomination: Podzols* |
| Tundra humus soils with solifluction | **Tundra soils**: the long and intense cold winters freeze the humidity of the soil during a number of months during the year, bulk material then is formed by particles mechanically broken. Peat is abundant due to the slow vegetal decomposition process. These soils do not have clear profiles but they form slight layers of sandy clay and raw humus. | FAO nomination: e.g. Gelic Gleysols |

TABLE RT1. ZONOBIOMES AND CORRESPONDING ZONAL SOIL TYPE AND ZONAL VEGETATION (WALTER, 1984)[3]

| Zonobiome | Zonal soil type | Zonal vegetation |
|---|---|---|
| ZB I | Equatorial brown clays (ferralitic soils, latosols) | Evergreen tropical rain forest |
| ZB II | Red clays or red earths (savanna soils) | Tropical deciduous forest or savannas |
| ZB III | Sierozems | Subtropical desert vegetation |
| ZB IV | Mediterranean brown earths | Sclerophyllous woody plants |
| ZB V | Yellow or red podzolic soils | Temperate evergreen forest |
| ZB VI | Forest brown earths and gray forest soils | Nemoral broadleaf-deciduous forest (bare in winter) |
| ZB VII | Chernozems to sierozems | Steppe to desert with cold winters |
| ZB VIII | Podzols (raw humus-bleached earths) | Boreal coniferous forest |
| ZB IX | Tundra humus soils with solifluction | Tundra vegetation (treeless) |

## BI–1.3. TOPOGRAPHY

Topographic relief is an important characteristic that influences the development of soils and vegetation and is therefore of some interest when trying to develop a coherent description of a biosphere system. Primary categories and related general topographic characteristics used to identify a particular region are summarised in Table TI.

TABLE TI. TOPOGRAPHICAL CATEGORIES

| | |
|---|---|
| Geographical Context | Coastal<br>Inland |
| Altitude | Lowland<br>Upland<br>High Mountain |
| Landform | Plain<br>Subdued<br>Marked Slopes |
| Localised Erosion | Limited<br>Fluvially incised<br>Glacially incised |

## BI–1.4. WATER BODIES

Water in its three different states is a major element in all the components of the biosphere and one of the basic factors that permits the existence of living organisms. Water is present in the atmosphere and in the lithosphere (glaciers, surface waters and ground waters). Table WI identifies a variety of water body types that may be present in the biosphere system.

[3] Defined for natural ecosystems and semi-natural systems not yet substantially influenced by man

TABLE WI. WATER BODIES TYPES

1. Surface Water Bodies
   - Natural:
     - Rivers
     - Lakes
     - Springs
     - Streams
     - Wetlands
     - Estuaries
     - Seas
     - Oceans
   - Artificial:
     - Canals
     - Harbours
     - Wells
     - Reservoirs
     - Distribution/storage water systems
2. Subsurface Water Bodies
   - Variably saturated zone
   - Saturated zone
3. Ice Bodies
   - Continental
   - Shelves
   - Corrie and valley glaciers
   - Sea Ice

## BI–1.5. BIOTA (FAUNA AND FLORA)

A biome describes a set of ecosystems within a geographical region exposed to the same climatic conditions and having dominant species with a similar life cycle, climatic adaptation, and physical structure (Botkin, 1986). The types of organism that are present at a particular location depend on the environment and on certain aspects of the history of our planet. Organisms will have adapted both physically and metabolically to their local environment, and it is possible to categorise the organisms by external shape and internal form. This is called physiognomic classification.

An ecosystem may be defined as the smallest unit of the biosphere that has all the characteristics required to sustain life. It therefore corresponds to an assemblage of populations of biota, grouped into communities and interacting with each other and their local environment. With this in mind, a biome can be defined as a physiognomic class of a set of ecosystems.

A simple basis for classifying ecosystems is according to type of media. Thus, for example, a general distinction can be made between terrestrial and aquatic biomes. **Terrestrial** biomes are often defined by the vegetation types that dominate the community (physiognomy) or, as defined in this Annex, in terms of climate, type of soil/s, and vegetation (see for example (Walter, 1984)). **Aquatic** ecosystems fall into two main categories: fresh water and marine. Freshwater ecosystems, such as lakes, rivers, marshes and swamps are typically considered as part of terrestrial biomes. Exceptions to this simple classification, include “estuaries” (unique in that they lie at the interface of the terrestrial and marine biomes) and, “hypersaline” ecosystems (unique in that they are dominated by a complex microbiota, many species of which require exceedingly high concentrations of salt). Herein, both of these are classified under aquatic.

From the perspective of describing biosphere systems relevant to the evaluation of potential human exposure, it is important that the classification scheme should not simply be restricted to natural ecosystems. Defining categories in terms of the degree of ‘management’ by humans therefore imposes a more comprehensive higher-level structure. Any number of such categories could be defined, ranging from no management to a high degree of control. For simplicity, however, three main categories are identified here: (a) no-management, referring to “natural systems”; (b) low-management, referring to “semi-natural systems” and; (c) high-management, referring to “managed systems”. The overall classification scheme for identification of ecosystem types is summarised in Table BI.

TABLE BI. ECOSYSTEMS CLASSIFICATION

<table>
<tr><td colspan="4">NATURAL SYSTEMS (Rambler et al., 1989)</td></tr>
<tr><td>Terrestrial Ecosystems</td><td>Tropical rain forest<br>Tropical seasonal forest<br>Temperate evergreen forest<br>Temperate deciduous forest<br>Boreal forest<br>Woodland and shrubland<br>Savannah<br>Temperate grassland<br>Tundra and alpine meadow<br>Desert scrub<br>Rock, ice and sand</td><td>Aquatic Ecosystems</td><td>Open oceans<br>Upwelling zones<br>Algal bed<br>Coral reef<br>Thermal vents<br>Swamp and marsh<br>Lake and Rivers<br>Littoral marine<br>Continental shelf or slope benthic<br>Abyssal benthic<br>Estuaries<br>Brackish</td></tr>
<tr><td colspan="4">SEMI-NATURAL SYSTEMS(Countryside Commission, 1990; DoE, ITE, IFE, 1990)</td></tr>
<tr><td>Terrestrial Ecosystems</td><td>Upland heath<br>Upland smooth grass<br>Upland coarse grass<br>Blanket bog<br>Bracken<br>Lowland grass heath<br>Neglected grassland</td><td>Aquatic Ecosystems</td><td></td></tr>
<tr><td colspan="4">MANAGED SYSTEMS (Countryside Commission, 1990, DoE-ITE-IFE, 1990, Cole and Brander, 1986, Michael, 1987)</td></tr>
<tr><td colspan="2" rowspan="4">Terrestrial Ecosystems</td><td>Managed grasslands</td><td>– Improved grassland<br>– Rough grassland</td></tr>
<tr><td colspan="2">Field crop ecosystems / Cultivated land<br>Tree crop ecosystems<br>Greenhouse ecosystems</td></tr>
<tr><td>Bioindustrial ecosystems (Cole and Brander, 1986)</td><td>– Intensive dairying<br>– Intensive beef-cattle production<br>– Pig industry<br>– Poultry</td></tr>
<tr><td colspan="2">Continuous Built-up land<br>Suburban development<br>Urban open space<br>Hard cover<br>Transport routes</td></tr>
<tr><td colspan="2">Aquatic Ecosystems<br>(Michael, 1987)</td><td colspan="2">Fresh water fish ponds<br>Man-made reservoirs<br>Autotrophic mass cultures of micro-algae<br>Managed coastal waters for oysters</td></tr>
</table>

BI–1.6. HUMAN ACTIVITIES

One of the fundamental principles of ecology is that life patterns reflect the patterns of the physical environment. In terrestrial communities, vegetation patterns are influenced by climate (e.g. moisture and temperature) and soil. Of all forms of life, mankind is the least bound by environmental limitations, with the capacity to develop artificial environments across a wide range of conditions.

Humans have a limited ability to change climate, except perhaps sporadically (e.g. by cloud seeding) or inadvertently (e.g. by pollution). Local effects on climate may be associated with large conurbations and power generating facilities or, on a smaller scale, by windbreaks and glasshouses. The basic context established by physical environment (topography, landforms etc.) may also be modified – at a cost – by engineering activity, but it remains unusual for major changes to be undertaken unless there is a compelling social or economic incentive. Furthermore, although hydraulic engineering may strongly influence the availability and distribution of water, the existence of water resources nevertheless plays an important role in determining human activity. Broadly speaking, therefore, human activities will adapt to the constraints established by the physical environment but, with the support of tools, shelter, clothing and energy resources, communities can be successfully established within a variety of climates and physical settings.

The identification and description of human communities and activities is a necessary component of the biosphere system description, for two primary reasons. First, it indicates the extent to which human activities and man-made communities have disturbed or replaced natural systems. Throughout the world, natural biomes have been superseded by agriculture and urbanisation. One result of this is that, over large regions, natural hydrological and biogeochemical pathways and processes have been modified significantly by land and water management practices. Hence, the assumed influence of mankind on ecological communities and the transport and cycling of materials clearly needs to be taken into account in the description and modelling of hypothetical future biosphere systems for long-term radiological impact assessment[4]. Second, consideration of the assumed relationship of human communities to the biosphere is important in describing the manner in which local (and potentially contaminated) environmental resources are exploited. Such issues are relevant to characterising the behaviour of hypothetical exposed groups as a basis for estimating doses and risks.

In identifying and characterising human behaviour for the purposes of the biosphere system description, a primary consideration is the extent to which it is assumed that the environment is regulated by human activities. If the degree of management is ‘none’ or ‘low’, the biosphere system may be considered to be in a natural or semi-natural state respectively, whereas more intensively managed systems will tend to be artificially controlled and maintained. In addition, the socio-economic basis on which a community operates can be important in determining the extent to which it depends for its survival on locally available resources. This, in turn, will influence the variety of activities undertaken within the biosphere system, thereby, the potential exposures to contaminated environmental media.

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[4] It is recognised that temporal variations may be important; all types of biosphere system can be exposed to significant short-term transformation, both naturally (e.g. by fire) or artificially (fallow agricultural land, forest clearance). Explicit characterisation of the effects of transitions associated with human actions tends not to figure centrally in the development of representative indicators for potential long-term radiological impact. Nevertheless, scoping estimates of the potential significance (whether transient or long-term) of such changes may be of some interest.

Table HI presents a broad classification of human community types, defined according to both their assumed degree of independence/trade and the intensity of environmental modification and maintenance. The justification for identifying and adopting a particular community type as the basis for biosphere definition and subsequent radiological assessment is likely to depend, at least partially, on the physical environmental context (climate, landform, water resource availability etc.). In addition, relevant considerations will include components of the overall assessment context, including the underlying assessment philosophy and the perceived significance of the choice of the endpoints or purpose of the assessment.

The development of descriptions of the effect of human behaviour on the biosphere system, as well as the classification of actions relevant to human exposure, should be broadly consistent with fundamental assumptions regarding the type of community that is present.

TABLE HI. CLASSIFICATION OF HUMAN COMMUNITY TYPES BASED ON SOCIO-ECONOMIC AND ENVIRONMENTAL CONTROL CONSIDERATIONS

<table>
<tr><th>Trading</th><th>Biosphere Control</th><th>Community Types</th><th>Community activities* in relation to the system</th></tr>
<tr><td rowspan="3">None</td><td>None</td><td>Nomadic / Hunter-gatherer</td><td>Hunting, Gathering, Fishing, Nomadic herding, Direct use of surface waters</td></tr>
<tr><td>Low</td><td>Primitive Agricultural</td><td>Hunting, Gathering, Fishing, Grazing, Low yield crop production, Selective Forestry, Direct use of water resources</td></tr>
<tr><td>High</td><td>‘Subsistence’ Agriculture</td><td>Crop production, Cattle, Recycling of residues, Use of wood resources, Use of water resources</td></tr>
<tr><td rowspan="2">Small-scale</td><td rowspan="2">High</td><td>Small farming communities living off local produce</td><td>Edible and non-edible crop production, Animal Husbandry/Grazing, Recycling of residues, Use of wood resources, Use of water resources</td></tr>
<tr><td>Small farming community – external foodstuffs permitted</td><td>Edible and non-edible crop production, Animal Husbandry/Grazing, Recycling of residues, Use of wood resources, Use of water resources</td></tr>
<tr><td rowspan="10">Large-scale trading</td><td rowspan="2">Low</td><td>Urban with Domestic Gardening</td><td>Use of water resources, Gardening, Amenity grass management.</td></tr>
<tr><td>Industrial</td><td>Use of water resources for industrial production</td></tr>
<tr><td rowspan="8">High</td><td>Commercial Agriculture</td><td>Use of water resources</td></tr>
<tr><td>Agriculture/ Horticulture/ Silviculture</td><td>Edible and non-edible crop production, Animal Husbandry/Grazing, Deciduous/Coniferous woodland management</td></tr>
<tr><td>Aquaculture</td><td>Fish farming,<br>Water plant farming</td></tr>
<tr><td>Climate controlled farming/ “Zero-land” farming</td><td>Hydroponic crop production,<br>Permanently stabled animals,<br>Glasshouse horticulture</td></tr>
<tr><td>Large scale monoproduction</td><td>Edible and non-edible crop production</td></tr>
<tr><td>Market Town</td><td>Range of small-scale commercial agricultural practices</td></tr>
<tr><td>Mineral Exploration / Exploitation</td><td>Land movement, Use of water resources</td></tr>
</table>

* Note: Use of land for residential purposes, and potential exploitation of local water resources, are assumed possible in association with any of the different classes of activities.

## BI–2. TYPE II TABLES OF BIOSPHERE SYSTEM COMPONENT CHARACTERISTICS

In what follows, a series of checklists is presented, which are intended to provide a self-consistent basis for defining the characteristics of identified biosphere system components. The naming scheme (CII, BII etc.) adopted in presenting the Tables is intended to be consistent with that adopted in the description of the procedure for System Identification (see also Section 3 of the main text).

### BI–2.1. CLIMATE AND ATMOSPHERE

Climate characteristics are usually described by meteorological data referring to a specific period of time and location. Depending on the time period over which data are collected and the area of the region being identified/described, some characteristics (usually given as average values of one or several "representative" stations) may be of only marginal significance for incorporation in models for radiological impact assessment over long time periods. Nevertheless, it may still be appropriate to account for such characteristics as contributors to the overall uncertainty in the description of climate for the assumed biosphere system. Table CII identifies common climate characteristics, typical time periods over which meteorological data may be obtained, and spatial/aspect variables that could affect those data. As far as possible, some degree of variability should be accepted in choosing representative data for the biosphere system in order to reflect uncertainties that may need to be taken into account in developing the conceptualised representation of the biosphere system.

TABLE CII. CLIMATE CHARACTERISTICS

- Climate Characteristics
  - Temperature
  - Precipitation (Rainfall/Snowfall/Occult)
  - Pressure
  - Wind speed and direction
  - Solar radiation (hours of sunshine)
- Temporal Variability of Climate
  - Diurnal
  - Seasonal
  - Interannual
  - Decadal
- Spatial Variability of Climate
  - Latitudinal
  - Longitudinal (continentality)
  - Altitudinal
  - Aspect-related

### BI–2.2. NEAR-SURFACE LITHOSTRATIGRAPHY

#### BI–2.2.1. Geology

General characteristics of the parent rock within the near-surface environment, including both the consolidated part, and any overlying unconsolidated region, are identified in Table GII.

TABLE GII. GEOLOGY CHARACTERISTICS

| |
|---|
| • Lithostratigraphy (vertical and horizontal variation)<br>• Fracture systems (vertical and horizontal variation)<br>• Weathering (degree of)<br>• Erodability<br>• Mineralogy |

### BI–2.2.2. Edaphology (soils and sediments)

The primary common characteristics of soils and sediments are summarised in Table SII.

TABLE SII. SOIL AND SEDIMENTS CHARACTERISTICS

| |
|---|
| • Stratification (i.e. horizons)<br>• Composition (organic content, mineralogy)<br>• Texture<br>• Fracture system<br>• Areal variation<br>• Weathering (degree of) |

## BI–2.3. TOPOGRAPHY

Specific generic characteristics describing topographic features at any specific location are summarised in Table TII.

TABLE TII. TOPOGRAPHY CHARACTERISTICS

| |
|---|
| • Altitude<br>• Slope<br>• Erodability<br>• Deposition rates |

## BI–2.4. WATER BODIES

Table WII summarises generic water body characteristics relevant to providing a comprehensive description of water bodies within the biosphere.

TABLE WII. 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)
  - Snowpack development
  - Water body freezing
- Hydrochemistry
  - Composition of:
  - Major anions and cations
  - Minor anions and cations
  - Organic compounds
  - Colloids
  - pH and Eh

## BI–2.5. BIOTA (FAUNA AND FLORA)

Within an identified ecosystem, the individual component communities can be described and characterised. Table BII provides a scheme for describing and characterising plants and animals relevant to providing a comprehensive description of the biota within the biosphere.

TABLE BII. ECOSYSTEM COMMUNITY CHARACTERISTICS (TERRESTRIAL AND AQUATIC COMPONENTS)

- NET PRIMARY PRODUCTIVITY (Rate at which energy is bound or organic material created by photosynthesis after accounting for respiration per unit area per unit time)
- NET SECONDARY PRODUCTIVITY (Net productivity of heterotrophic organisms – animals and saprobes)
- BIOMASS/STANDING CROP (Dry weight per unit area)
  - Plants
  - Animals
  - Other organisms
- CROPPING (Rate of removal by humans)
  - Animals and animal products
  - Plants and plant products
  - Other organisms and their products
- POPULATION DYNAMICS
  - Plants
  - Animals
  - Other organisms

TABLE BII. CONTINUED

- VEGETATION CANOPIES
  - Physical structure
  - Interception of light, water, aerosols, vapours and gases
- PLANT ROOTS
  - Structure and distribution with depth
  - Absorption of nutrients and water with depth
- ANIMAL DIETS
  - Composition
  - Quantity
- BEHAVIOURAL CHARACTERISTICS (e.g. the part of the ecosystem in which an animal forages and the time it spends foraging in different parts of the ecosystem, including management aspects where applicable)
  - Animals
  - Other mobile organisms
- CHEMICAL COMPOSITION and CHEMICAL CYCLES (Including sources and sinks)
  - Major nutrients
  - Minor nutrients
  - Trace elements
- METABOLISM
  - Animals
  - Plants
  - Other organisms

*Note: VARIATION WITH SPACE is dealt with under Extent and Heterogeneity) and VARIATION WITH TIME (Diurnal, Seasonal, Annual or other) is dealt in the appropriate descriptive characteristics.*

## BI–2.6. HUMAN ACTIVITIES

The description of human communities and activities is a necessary component of the biosphere system description for two primary reasons. First, it indicates the extent to which human activities and man-made communities have disturbed or replaced natural systems. One result of this is that, over large regions, natural hydrological and biogeochemical pathways and processes have been modified significantly by land and water management practices. Hence, the assumed influence of mankind on ecological communities and the transport and cycling of materials clearly needs to be taken into account in the description and modelling of hypothetical future biosphere systems for long-term radiological impact assessment[5]. Second, consideration of the assumed relationship of human communities to the biosphere is important in describing the manner in which local (and potentially contaminated) environmental resources are exploited. Such issues are relevant to characterising the behaviour of hypothetical exposed groups as a basis for estimating doses and risks.

[5] It is recognised that temporal variations may be important; all types of biosphere system can be exposed to significant short-term transformation, both naturally (e.g. by fire) or artificially (fallow agricultural land, forest clearance). The nature of regulatory risk criteria is such that explicit characterisation of the effects of transitions associated with unpredictable, one-off events resulting from human actions tends not to figure centrally in the development of representative indicators for potential long-term radiological impact. Nevertheless, scoping estimates of the potential significance (whether transient or long-term) of such changes may be of some interest.

TABLE HII. HUMAN COMMUNITY CHARACTERISTICS

- Population
  - Age distribution
  - Density
  - Economical Sectors distribution
  - Diet
- Human behaviour
  - Activities in relation to the system:
    *Table HIIa identifies relevant activities that may be important in terms of their influence over the different components of the system.*
  - Activities in relation to exposure:
    *Table HIIb identifies activities in relation to potential exposure modes and pathways. Characteristic parameters associated with quantifying exposure (e.g. exposure duration, rate of intake, shielding factors, location with respect to the source etc.) are also indicated.*

TABLE HIIA. ACTIVITIES IN RELATION TO THE BIOSPHERE SYSTEM

| Biosphere System Components | Human Influence on Biosphere System Components |
|---|---|
| Climate Atmosphere | Change composition of the atmosphere (local, global scale)<br>Create a local microclimate<br>Controlled ventilation of buildings (Air) |
| Geological Media | Quarrying<br>Mining |
| Soils / Sediments | Homogenisation (ploughing / tilling)<br>Change composition (soil improvement and fertilisation, including crop residues and animal waste)<br>Transport/transformation (dredging and disposal of sediment)<br>Impermeable surfaces / artificial drainage |
| Topography | Alteration of erosion rates |
| Water Bodies | Change the physical shape and flows (damming)<br>Change the effective volume/level (artificial mixing, water abstraction)<br>Transport of water (pumping and distribution of water)<br>Change the composition (waste water discharge) |
| Natural and Semi-Natural Ecosystems (Terrestrial/ Aquatic) | Fire control (e.g. periodic burning / firebreaks)<br>Pest / weed control<br>Use for grazing<br>Hunting/fishing |
| Managed Ecosystems (Terrestrial/ Aquatic) | Planting<br>Irrigation<br>Cropping<br>Husbandry practices (e.g. seasonal relocation)<br>Feeding and watering |

The extent to which any of the activities identified in Table HIIa is practised by the local human community, and their detailed characterisation, will depend on fundamental assumptions relating to the type of community and its technological capabilities. The list presented here is not considered exhaustive, but is intended to provide a working basis for developing a comprehensive description of such activities as part of a coherent overall system description.

## TABLE HIIB. HUMAN ACTIVITIES LEADING TO POTENTIAL RADIATION EXPOSURE

| Biosphere system components[1] | Potential Exposure Mode -> Exposure Routes | Related Activities | Relevant Parameters[2] |
|---|---|---|---|
| Atmosphere | *Inhalation:* Breathing | All activities, indoors and outdoors | B |
| | *Ingestion:* Particulate deposition on foods, surfaces | Eating, recreational activities | B, D, H |
| | *External:* Submersion | All activities, indoors and outdoors from airborne concentrations | A, C, F, G |
| Geological media | *Inhalation:* Resuspension of dust | Mining, Quarrying | A, B, E, G |
| | *Ingestion:* Incidental ingestion | Contamination of food / fingers etc. in working environment | B, D, H |
| | *External:*Exposure to walls, ceiling and floor | Mining, Quarrying | A, C, F, G |
| Soils | *Inhalation:* Gaseous release into air (Volatile radon.) | All activities, indoors and outdoors | A, B, E |
| | *Inhalation:* Soil/dust resuspension | Soil disturbance activities (e.g. ploughing, walking, outdoor activities, indoor exp. from dirt tracked in) | A, B, E<br>Particle size |
| | *Ingestion:* Incidental soil ingestion | Gardening, eating, recreational activities | A, B, H |
| | *External:* External irradiation (including dermal contact) | Activities over/near contaminated soil<br>Living in contaminated buildings | A, C, F, G |
| Sediments | *Inhalation:* Resuspension of dried sediments | Dredging (includes tank cleaning), farming activities after land application | A, B, E |
| | *Inhalation:* Spray of suspended sediment | Irrigation spray, showering | B |
| | *Ingestion:* Incidental ingestion of suspended sediments | Drinking water, bathing, swimming, cooking | B |
| | *Ingestion:* Incidental ingestion of dried sediments | Gardening or eating fresh vegetables from deposition areas downwind of dried sediments, recreational activities on dried sediments | B, H |
| | *External:* Gamma exposure from sediments | Activities near water bodies (including tanks), Activities on dried sediments, swimming, | A, C, F, G |
| Water Bodies | *Inhalation:* Spray, Aerosols, Volatile | Spray (Irrigation, surface waters), Domestic (showering/sauna/cooking) | A, B, E |
| | *Ingestion:* Drinking | Drinking | B |
| | *Ingestion:* Incidental ingestion | During bathing/swimming | A, B |
| | *Ingestion:* Eating | Cooking practices | B |
| | *External:* Submersion in water<br>External from water bodies | Bathing, swimming,<br>working near contaminated water bodies (including water tanks and filtration systems) | A, C, F, G |
| | *Dermal Absorption:* Submersion in water | Swimming, bathing, interception of irrigation spray | B |
| | *Inhalation:* Animal-derived particulates from incineration or cooking | Incineration of waste products, cooking, occupational use of animal products | A, B, E |
| Fauna | *Ingestion:* Food | Eating (meat, offal, milk products, eggs, gelatin)<br>Drinking milk | B |
| | *External:* Gamma exposure from animals/animal products | Animal husbandry, processing/storage, wearing clothes | A, C, F, G |
| Plants | *Inhalation:* Particulate from combustion | Fuel burning, ecosystem control by fire | A, B, E, G |
| | *Ingestion:* Eating food | Eating plant products<br>Drinking plant-based drinks | B |
| | *External:* Gamma exposure from plants/plant products | Working/Recreation in fields, storage/processing, wearing clothes, living in buildings with material or furniture contaminated | A, C, F, G |

Note 1: The generic subset of biosphere system components that are potentially contaminated environmental media.
Note 2: Explanation of Parameters (final column) relevant to the Quantitative Description of Pathways.
A - Exposure Duration (hrs, yrs etc.)
B - Rate of Intake (kg/yr, g/hr etc.)
C - Shielding of Source (yes/no, effective thickness, shielding factor)
D - Deposition Rate ($g/m^2/yr$ etc.)
E - Resuspension/Release Rate (g(soil)/cu. m air, 1/m, g/hr etc.)
F - Geometry of Source (infinite plane, line, sphere, semi-infinite cloud etc.; source area/volume - sq. m)
G - Relation to Source (Distance - m; Relation to source - beside, above, below, in etc.)
H - Age-specific Information Important (because children may have greater total intake rates than adults (i.e. in situations where children behave fundamentally differently from adults)

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## ANNEX BII
## GUIDANCE ON THE DEFINITION OF CRITICAL AND OTHER HYPOTHETICAL EXPOSED GROUPS FOR SOLID RADIOACTIVE WASTE DISPOSAL

### BII–1. INTRODUCTION

#### BII–1.1. BACKGROUND

There is a measure of international consensus regarding general safety principles, including radiological protection objectives, applicable to radioactive waste management practices. However, there is a lack of consensus regarding how best to interpret such objectives (e.g. for regulatory compliance purposes) in the context of radioactive waste disposal, particularly for releases to the environment that might take place in the distant future. The structure of the BIOMASS Theme 1 programme reflects the common interest of parties involved in radioactive waste management in establishing a coherent approach to the development and quantitative application of safety acceptance criteria for waste disposal facilities.

A variety of complementary safety indicators for geological disposal systems could be adopted (IAEA, 1994; ICRP, 1998b), several of which relate directly to human exposure. Indeed, the detailed approaches taken in different countries exhibit a range of features. Nevertheless, the application of radiological protection objectives has customarily been interpreted to include at least some form of restriction on the radiation doses and/or risks incurred by people who could be exposed as a result of the migration of radionuclides from a repository following its closure.

Principles established by the International Commission on Radiological Protection (ICRP) form the foundation for regulatory frameworks and quantitative standards adopted in many countries. The ICRP's 'System of Radiological Protection' (ICRP, 1991) for proposed and continuing practices involving the possibility of radiological exposure (including the disposal of solid radioactive waste) requires that:

(a) *No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.*

(b) *In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be achieved should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), so as to limit the inequity likely to result from inherent economic and social judgements.*

(c) *The exposure of individuals resulting from the combination of all the relevant practices should be subject to limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances.*

Quantitative radiological assessment plays a role at each stage in the implementation of the ICRP system. In particular, in order to demonstrate compliance with limits and constraints on individual dose (or risk) for releases of radioactive materials to the environment, satisfactory assurance needs to be provided that corresponding levels of exposure will be not be exceeded. However, uncertainties in characterising behaviour, and hence in estimated exposure, are significantly greater where the assessment encompasses the exposure of hypothetical individuals from future releases rather than actual critical groups within real populations exposed to present-day discharges (Charafoutdinov et al., 1998; ICRP, 1998b).

Descriptions of biosphere systems (particularly in so far as they are influenced by human activity) and human behaviour relevant to long-term radiological safety assessments will therefore inevitably incorporate a certain amount of hypothesis and/or speculation. In the context of a radioactive waste repository, where releases may take place far into the future, this places exacting demands on the justification of assumptions and hypotheses that underlie the evaluation of radiological exposures.

In making a radiological assessment for hypothetical future exposures, it is necessary to characterise, *quantitatively*, aspects of human behaviour that are relevant to the application of safety acceptance criteria. 'Relevant' behaviour in the context of releases from solid radioactive waste disposal facilities includes that which gives rise to exposure (e.g. via ingestion, inhalation, or direct external irradiation) from environmental contamination that may be present at some future time. In addition, the assessment should also consider the potential impact of the behaviour of human society on the biosphere itself (e.g. agricultural and other resource exploitation or land use practices).

A common approach is to define one or more hypothetical 'exposed groups', the sizes of which may range from a single individual to an entire community. Members of such exposed groups may be characterised in terms of their sharing of one or more common behavioural characteristics (diet, habits, location etc.), or simply by a similarity in their overall dose or risk. For consistency with terminology used elsewhere in the context of radioactive discharges to the environment the hypothetical exposed group regarded as being indicative of the highest exposures at some time in the future is often identified as the 'critical group'.

Guidance from international agencies and national regulatory bodies has often appealed to reason as the basis for identifying and defining potentially exposed individuals. However, whereas quantitative radiological standards for long-term safety performance exist, no definitive guidance has been provided on what constitutes a 'reasonable' description of hypothetical future human behaviour in the context of demonstrating compliance with such standards. Moreover, it is not helpful to look elsewhere for guidance; although other types of environmental hazard may be similarly persistent, the use of quantitative measures of impact on such timescales (perhaps many thousands of years after the original disposal of the waste) as a basis for decision making is almost unknown outside the field of radioactive waste management.

### BII–1.2. BASIS FOR THE DEVELOPMENT OF GUIDANCE

The International Atomic Energy Agency's general safety principles (IAEA, 1995) state that the overall objective of long-term safety assessments for radioactive waste disposal should be to provide assurance that *"the predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today"*. This general safety principle is also used in various ICRP guidance documents, see for example (ICRP, 1998b), and in many national regulations. It is not possible to make a precise identification of a particular population group exposed to discharges from a repository at some time in the far future. Rather, the aim of the biosphere component of performance assessment for the disposal system should be to develop suitably robust, representative indicators of what the dose or risk incurred by future groups might be, and thereby to provide a sufficient level of assurance that future individuals are afforded a level of protection consistent with that required today.

Indeed, contrary to the situation that often exists in relation to present-day waste discharges, it is not possible to 'validate' calculated radiological impacts as being realistic estimates of actual exposures in the long term. Hence, the biosphere(s) and associated descriptions of human behaviour adopted for the purposes of performance assessment in relation to waste disposal cannot provide absolute assurance that rigid quantitative criteria will be met for every possible eventuality. Instead, they can at best be seen as 'measuring instruments' of potential future radiological impacts, for comparison with present-day standards of protection. The use of representative indicators, or 'measuring instruments', of future dose or risk is akin to ICRP's suggested use of "stylised" approaches for estimating very long-term repository performance (ICRP, 1998b).

The BIOMASS Methodology is intended as a comprehensive basis for the development of quantitative radiological assessments consistent with general safety principles. The guidance provided in this Annex is intended to support this Methodology. It has been used to develop the BIOMASS approach to the definition of hypothetical exposed groups. Broadly, the aim is that biosphere systems representative of the future should be populated with hypothetical 'exposed groups' that are consistent with the system description and with the overall context and objectives of the assessment.

### BII–1.3. PURPOSE OF THIS ANNEX

The purpose of this Annex is to review methods for defining present-day and hypothetical future exposed groups for solid radioactive waste disposal, and to provide guidance on the application of such methods in assessing radiological exposure. The document reviews existing guidelines related to the definition of critical groups, and identifies and explores issues (e.g. the underlying assessment context, and criteria and compliance standards) that may affect the choice of approach. Consideration is given to the implications of attempting to characterise aspects of future human behaviour that are inherently unpredictable, yet which must be quantified in order to perform radiological safety assessments.

The component of the assessment process addressed here is therefore the justification of future representations of human society as a basis for the estimation of long-term safety performance indicators. This includes consideration of whether and how to define 'individuals' or 'groups' within the society in order to undertake such calculations. A range of practical problems involved in implementing long-term safety assessments are identified and considered, covering a broad range of issues and concerns that together provide a basis for further developments. Relevant properties of the biosphere that affect human behaviour are also addressed.

Those aspects of human behaviour that shape the nature and properties of the biosphere, and which thereby represent important factors determining the fate of possible future releases, have not been specifically addressed. Hence, as far as the characterisation of hypothetical exposed groups and their environment is concerned, it is assumed that societies with specific systems of biosphere resource utilisation (e.g. agriculture, hunting and fishing) are pre-defined as part of the underlying assessment basis.

Section BII–2 summarises the underlying considerations involved in the identification and quantitative definition of hypothetical exposed groups for the long-term radiological assessment of land-based solid radioactive waste disposal. In particular, the details of any safety assessment are recognised as being dependent on the 'context' of that assessment. Section BII–2.1 therefore provides a brief description of the relevant components of the assessment context. Existing international guidelines can also guide the detailed development of exposed group descriptions; the current situation, in so far as it applies to long-term safety assessments, is summarised in Section BII–2.2. A summary of relevant lessons learned from a short survey of national regulatory guidance is provided in Section BII–2.3.

Two complementary approaches to describing hypothetical exposed groups, each aimed at providing a robust and coherent assessment framework, are distinguished in Section BII–3. The likely advantages and disadvantages associated with each alternative are discussed. Finally, the primary guidance arising from this report, based on the preceding analyses, is then elaborated in Section BII–4.

## BII–2. UNDERLYING CONSIDERATIONS FOR QUANTITATIVE ASSESSMENT

### BII–2.1. ASSESSMENT CONTEXT

Radiological safety assessments are not performed in a 'vacuum' but, rather, in support of specific stages of a decision making process. It is therefore important that they should be formulated so as to be 'fit for purpose'. Hence, in developing and applying any guidance relating to the definition of future human behaviour for such assessments, a prime consideration is the overall context within which the assessment is to be performed.

Nevertheless, a common weakness of many performance assessments has been the use of approaches, models and data that are not obviously well matched to the specific question(s) being addressed (BIOMOVS II, 1996). Clearly, to apply a 'reference' set of exposure characteristics resembling, for example, those of coastal communities in Scandinavia to people living in the south-western regions of the USA would be no more appropriate than applying a northern temperate coastal biosphere to a disposal site in the desert. A successful biosphere assessment needs to be consistent with the underlying objectives of the assessment, the endpoints that are to be evaluated and the characteristics of the release from the geosphere. These issues are themselves influenced by national regulations, the stage of development of the repository programme and the major features of the disposal system represented in the performance assessment. Moreover, the basis on which safety criteria themselves are determined may have a significant impact on the development of consistent and appropriate characterisations of hypothetical exposed groups.

The BIOMASS programme has recognised that a clear definition of the assessment context is essential for the development of an appropriate performance assessment. One aspect of the work within BIOMASS Theme 1 has therefore been to identify the relevant components of the 'assessment context' necessary for the coherent development of a biosphere system model to support safety assessments (see Part B). Components of the assessment context, and their relevance to the identification and characterisation of hypothetical exposed groups, are identified in the eight sub-sections that follow.

#### BII–2.1.1. Purpose of the assessment

The general purpose of the biosphere component of safety assessment for solid radioactive waste disposal is to determine the radiological significance of potential future releases of radionuclides. However, the level of detail and comprehensiveness required in identifying and justifying the assumed behaviour of hypothetical exposed groups will vary according to the specific aim of an assessment. For example, if simple calculations are required to test initial ideas for disposal concepts, it may be sufficient to base exposure estimates solely on an assumed drinking water pathway. Alternatively, an assessment intended to support a disposal licence application may demand a much wider variety of exposure pathways and approaches in order for radiological impacts to be adequately addressed.

#### BII–2.1.2. Endpoints of the assessment

If dose or risk to humans is selected as a relevant endpoint, rather than some other indicator of radiological impact (such as concentrations of radionuclides in environmental media), this implies a requirement to characterise human behaviour and exposure pathways. Some aspects of model and data choice concerning human exposure may depend on more detailed considerations related to such endpoints; for example, the impact may need to be evaluated in terms of a lifetime average annual dose or risk, rather than in terms of the annual exposure in any given year. This, in turn, can affect assumptions adopted in relation to potential variations of human behaviour or biosphere characteristics on different timescales, such as that of a human lifetime. In particular, such considerations might have an important impact on the emphasis given to exposures incurred by different demographic groups.

If the endpoint is individual dose or risk, rather than collective dose or some other population-integrated measure of radiological impact, it may be relevant to consider potentially sensitive subgroups of the exposed population. Such groups would be identifiable, for example, according to their use of particular natural resources, or through some other homogeneity criterion.

Although there is increasing interest in assessing the potential significance of radiological impacts of waste disposal practices on non-human biota (see, e.g. (IAEA, 1998; Smith et al., 1998)) the focus here is limited to radiological impacts expressed in terms of dose and risk to humans.

#### BII–2.1.3. Assessment philosophy

Even where the assessment endpoints are clearly defined, alternative approaches to addressing those endpoints may be possible. A coherent approach needs to be developed for all aspects of the assessment. A particularly important example concerns the degree of conservatism that is deemed to be appropriate in characterising the hypothetical behaviour of future exposed groups and/or individuals. Regulatory guidance on this issue is generally insufficient to define such behaviour for quantitative compliance assessments. However, the background against which quantitative safety standards are set can itself involve tacit assumptions about which groups within the population they are intended to protect. Further discussion of this question is included in Section BII–2.3, below.

### BII–2.1.4. Site context

The general location of a repository, combined with the particular design of the repository system, may have an important influence on the likely pathways for release, the type of biosphere system into which releases may occur, and the extent to which factors such as climate and ecological change can influence the impact of such releases. These, in turn, will affect the choices that need to be made in relation to the representation of human exposure pathways. In particular, it is necessary to ensure that the assumed human behaviour is consistent with the assumed biosphere system into which the release occurs.

### BII–2.1.5. Repository system

Except for human intrusion scenarios, features relating to the repository system will have only an indirect influence on the representation of human exposure pathways, predominantly through their influence on the radionuclides that may be released to the biosphere and the corresponding geosphere/biosphere interface.

### BII–2.1.6. Source term and geosphere/biosphere interface

In broad terms, the assumed mode and rate of release of radionuclides from the geosphere into the biosphere mainly influence choices made regarding the modelling of radionuclide transport and accumulation in the environment, rather than the representation of exposure pathways. However, detailed considerations relating to the modelling of the geosphere/biosphere interface and dispersion in the biosphere may assume greater importance in situations where the exposed group involves only a small number of individuals, or if homogeneity of exposure (rather than behaviour) is a critical concern in evaluating representative radiological impacts.

Specific modes of release, or particular radionuclides within the source term, may dictate consideration of exposure pathways that would perhaps not otherwise be included in the description of exposed groups. For example, radionuclides released to the biosphere in gaseous form may increase the emphasis given to inhalation of indoor air.

### BII–2.1.7. Time frames

An internationally-adopted safety principle is that waste disposal practices should provide for the protection of both current and future generations. The overall time frame to be addressed in demonstrating compliance with this principle may be established as part of the overall assessment context; in some regulatory guidance, however, only limited advice is given. Combined with information regarding the disposal system, site context and source term, the selection of a specific time frame can have a considerable impact on biosphere assessment, notably with respect to the treatment of environmental change, critical radionuclides and the geosphere/biosphere interface. In relation to radiological exposure calculations, assessment timescales beyond even a few tens, or at most hundreds, of years introduce profound uncertainty into any quantitative description of human behaviour. Assumptions related to human behaviour over longer time frames will therefore be largely speculative.

All these factors will affect the approach taken to representing the biosphere system and exposure pathways.

### BII–2.1.8. Societal assumptions

Basic assumptions relating to the type of society (e.g. agrarian or urban), community structures and level of technological development are fundamental to decisions made concerning the characterisation of future human behaviour. In addition, assumptions about the period of long-term institutional control over the disposal facility may influence the timeframes for the assessment and, thereby, affect assumptions underlying the definition of future exposed groups. Moreover, because human actions have a profound effect on the surface environment, societal assumptions are also very relevant to the identification, description and modelling of relevant biosphere systems. As with the overall assessment philosophy, advice relating to the choice of appropriate societal assumptions is not always incorporated in regulatory guidance. This can be deliberately intended to provide scope for the justification of assessment-specific assumptions and methods; nevertheless, it is important to recognise the degree of ambiguity of interpretation that can arise from failing to specify the societal assumptions under which compliance criteria are set.

## BII–2.2. EXISTING GUIDELINES FOR CHARACTERISING HUMAN BEHAVIOUR

### BII–2.2.1. Development of the critical group concept

The concept of the 'critical group' was adopted by ICRP in order to address the problem of setting quantitative limits on present-day or near-future discharges of radionuclides to the environment. In such circumstances, the actual doses incurred by members of the public will be variable due to a host of variable environmental factors, as well the intrinsic variability associated with differences in age, size, metabolism and habits. The underlying philosophy was to demonstrate compliance with a dose constraint based on estimated exposures for a particular population subgroup. This was originally explained as follows (ICRP, 1977):

> *"With exposure of members of the public it is usually feasible to take account of these sources of variability by the selection of appropriate critical groups within the population provided the critical group is small enough to be relatively homogeneous with respect to age, diet and those aspects of behaviour that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest dose equivalent, and the Commission believes that it will be reasonable to apply the appropriate dose-equivalent limit for individual members of the public to the weighted mean dose equivalent of this group. Because of the innate variability within an apparently homogeneous group some members of the critical group will in fact receive dose equivalents somewhat higher than the mean. However, because of the maximising assumptions used, the dose equivalent actually received will usually be somewhat lower than the estimated dose equivalent."*
>
> (ICRP Publication 26, (ICRP, 1977); paragraph 85).

Subsequently, the term 'critical group' has become widely used to describe a set of individuals who, because of their location and commonality in their behaviour and habits, are among the most highly exposed to releases from a nuclear facility. This approach was underlined in a recent policy statement (ICRP, 1998a), which notes that the concept "*was introduced into waste management to allow the individual doses delivered by a source to be assessed without the implied need to identify each individual separately*" (paragraph (3)(f) of ICRP Publication 77).

Whereas Publication 26 refers to the identification of a group whose *characteristics* are 'relatively homogeneous', the fundamental inhomogeneity in radiological protection terms is with respect to total dose, not the factors that determine dose. In other words, it is possible for two individuals with different combinations of age, location, metabolism, and habits to be assessed as incurring similar exposures to the same source. Thus, these two, outwardly different individuals could be classed into the same group due to their homogeneity of *exposure*. This point is emphasised in subsequent revisions of the ICRP recommendations (ICRP, 1991) where, in the context of 'normal exposures' from routine operations, it is stated that:

> *"In practice, almost all public exposure is controlled by the procedures of constrained optimisation and the use of prescriptive limits. It is often convenient to class together individuals who form a homogeneous group with respect to their exposure to a single source. When such a group is typical of those most highly exposed by that source, it is known as the critical group. The dose constraint should be applied to the mean dose in the critical group from the source for which the protection is being optimised..."*
>
> (ICRP Publication 60 (ICRP, 1991); paragraph 186).

For situations where it is reasonable to assume that the statistical variation of dose among the exposed population is comparable with that in a given present-day population (e.g. for routine discharges from planned or existing operational facilities), ICRP has developed specific guidance on the application of the critical group approach. In particular, attention has been given (paragraphs 67–69 of ICRP Publication 43 (ICRP, 1985a)) to interpreting the requirement for homogeneity within the critical group in the context of environmental monitoring (ICRP, 1985a). This guidance can be summarised as follows:

*(a)* *The dose limits are intended to apply to mean doses in a reasonably homogeneous group. The necessary degree of homogeneity in the critical group depends on the magnitude of the mean dose in the group as a fraction of the relevant source upper bound (or constraint). If that fraction is less than about a tenth, a critical group should be regarded as relatively homogeneous if the distribution of individual doses lies substantially within a total range of a factor of ten, i.e. a factor of about three either side of the mean. At higher fractions, the total range should be less, preferably no more than a factor of three.*

*(b)* *In an extreme case (for example when dealing with conditions in the far future, which cannot be characterised in detail), it may be convenient to define the critical group in terms of a single hypothetical individual.*

*(c)* *Usually, however, the critical group would not consist of one individual (as this would be statistically unrepresentative), nor would it be so large that it violated the homogeneity criterion.*

*(d)* *The size of a critical group will usually be up to a few tens of persons. In a few cases, where large populations are uniformly exposed, the critical group may be much larger.*

*(e)* *In habit surveys, it is not necessary to search for the most exposed individual within a critical group in order to base controls on that one person. The results of a habit survey should be regarded as an indicator of an underlying distribution and the value adopted for the mean should not be unduly influenced by the discovery of one or two individuals with extreme habits.*

*(f)* *In calculating doses to critical groups, metabolic parameters should be chosen to be typical of the age groups in the normal population rather than extreme values.*

#### BII–2.2.2. Application to solid radioactive waste disposal

The main emphasis in the guidance discussed above concerns application of the critical group concept to situations (principally effluent discharges) where exposures are virtually certain to occur, with a timing, magnitude and location that is predictable with some confidence. By contrast with such so-called ‘normal’ exposure situations, and because of the substantial uncertainties surrounding the occurrence and possible magnitude of future releases, the situations of concern in the long term following disposal of long-lived solid radioactive wastes are sometimes identified as ‘potential’ exposures (ICRP, 1991; 1993). Indeed, compared with the detailed interpretation of the critical group concept that has been developed in the context of normal exposures, the principles for defining human behaviour in relation to the assessment of potential exposures have received relatively limited attention.

The recent ICRP statement of policy on general issues related to waste disposal (ICRP, 1998) addresses the importance of protection of future generations from exposures resulting from present-day practices. In this context, attention is focused on the appropriate assessment quantities, rather than guidance on the means of evaluating them. Whereas it is noted that “*the relationship between dose and detriment [is] uncertain at times in the distant future*” (ICRP Publication 77 (ICRP, 1998a); paragraph 23), several quantities are considered potentially relevant in indicating the degree of protection afforded to future generations. These include the total detriment imposed on a defined generation, and the detriment imposed annually, or over a lifetime, on individuals represented by one or more hypothetical critical groups. Specifically, it is suggested that the annual individual effective dose (for normal exposure) and annual individual risk (for potential exposure) incurred by members of the relevant critical groups provide an adequate basis for comparing the limited detriment to future generations with that applied today (ICRP Publication 77 (ICRP, 1998a); paragraphs 68–69). This general approach was reiterated in ICRP Publication 81 (ICRP, 1998b), which provides guidance specifically for the disposal of long-lived solid radioactive waste.

The primary source of existing formal guidance from ICRP on critical groups in the context of solid radioactive waste disposal is Publication 46 (ICRP, 1985b). These recommendations have recently been clarified (but not substantially altered) in relation to broader considerations of radioactive waste disposal (including controlled release to the environment) (ICRP, 1998a; 1998b). The basic proposition embodied in the ICRP principles is summarised as:

> *“The critical group ... may comprise existing persons, or a future group of persons who will be exposed at a higher level than the general population. When an actual group cannot be defined, a hypothetical group or representative individual should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon present knowledge using cautious, but reasonable, assumptions.”*
>
> (ICRP Publication 46 (ICRP, 1985b); paragraph 46)

ICRP Publication 81 provides updated guidance relating specifically to considerations relevant to the disposal of waste in repositories (ICRP, 1998b) (rather than the more general policy on waste disposal (ICRP, 1998a), which includes effluent discharge). In addition to supporting the previous guidance (ICRP, 1985b) to adopt a ‘cautious, but realistic’ framework, Publication 81 addresses difficulties related to the very long time frames associated with solid waste disposal.

*Due to the long time-scales under consideration, the habits and characteristics of the critical group, as well as those of the environment in which it is located, can only be assumed. Consequently any such critical group has to be hypothetical. The habits and characteristics assumed for the group should be chosen on the basis of reasonably conservative and plausible assumptions, considering current lifestyles as well as the available site or region specific information. ... Moreover, in many cases, different scenarios, each associated with different critical groups, may have different probabilities of occurrence, and therefore the highest dose may not be linked to the highest risk. It is therefore important for the decision-maker to have a clear presentation of the different scenarios with their associated probability of occurrence or at least with an appreciation of the corresponding probability.*

(ICRP Publication 81 (ICRP, 1998b); paragraph 44)

However, ICRP (1998b) still does not provide specific guidance on what "reasonably conservative and plausible assumptions, considering current lifestyles as well as the available site or region specific information" means. Some of the possible interpretations and implications of this, and the other general ICRP guidance are considered below.

For example, coherence between assumptions relating to hypothetical exposed groups and the landscapes and environments they inhabit is important, but endless speculation regarding the possible impact of human behaviour on the biosphere is discouraged. Reference to present-day lifestyles is considered, consistent with approaches adopted elsewhere in radiation protection, but more generalised assumptions will tend to be appropriate as the timescales extend into the far future. An emphasis on homogeneity of habits and characteristics (including age) among members of a critical group is not a major concern in relation to long-term exposures, provided that due attention is given to the identification of suitably representative behaviour.

Sometimes, depending on the assessment purpose, it may be appropriate to provide an estimate of the population dose distribution associated with waste disposal. The background to this is explained (ICRP, 1998a) as follows:

*"To the extent that the justification of a practice involves collective dose, the Commission's policy requires an estimate of the total collective dose attributable to the practice, including the waste management and disposal operations."*

(ICRP Publication 77 (ICRP, 1998a); paragraph 35)

*"The unlimited aggregation of collective dose over time and space into a single value is unhelpful... The levels of individual dose and time distribution of collective dose may be significant factors in making decisions... The use of blocks of collective dose resulting from individual doses that are very small or occur at very remote times requires consideration."*

(ICRP Publication 77, (ICRP, 1998a); paragraphs 20–21)

*"[The Commission] does not recommend that the component of collective dose due to small individual doses should be ignored on the sole ground that the individual doses are small. [Nevertheless,] it may sometimes be possible in optimisation to disregard the collective dose from small doses to large numbers of people if the sources are widespread, because it may not be possible to reduce the collective dose with any reasonable deployment of resources."*

(ICRP Publication 77 (ICRP, 1998a); paragraph 56)

The potential number of people exposed to future releases from a repository, and the homogeneity of exposure across such a group, are not necessarily the primary considerations in assessing radiological exposures for direct comparison with regulatory benchmarks when these are expressed solely in terms of individual dose or individual risk. However, such factors may play a part in developing the 'multiple lines of reasoning' that are likely to be necessary in providing assurance that future individuals are afforded a level of protection consistent with that tolerated today. Furthermore, where regulatory benchmarks are in units of collective or population dose or risk, some indication of the potential number of people exposed and the numerical distribution of their exposure will need to be considered.

## BII–2.3. CRITERIA AND COMPLIANCE

### BII–2.3.1. National guidance on compliance standards for waste disposal

Regulatory approaches adopted in specific countries in respect of the disposal of long-lived solid wastes, together with guidance from relevant advisory bodies, represent attempts to provide practical interpretation of the general guidance on radiological protection principles provided by ICRP and others. In several cases (see e.g. (Burholt and Martín, 1988; JORF, 1991; HSK/KSA, 1993; SSI, 1998)), however, practical advice with respect to characterising human behaviour relevant to the evaluation of dose and/or health risk has either been very limited or is absent altogether.

There is general consensus in guidance from national regulatory authorities in different countries that radionuclide releases from repositories for solid radioactive wastes should be controlled so as to limit either individual doses or health risks. For long-term releases from repositories it is understood this 'control' is intended to be accomplished via passive, rather than active features of the engineered and natural barriers comprising the repository system. Guidance from the United Kingdom (Environment Agency et al., 1997), Spain (CSN, 1987), (Burholt and Martín, 1988), Sweden (SSI, 1998), the Canadian regulatory authorities (AECB, 1987) and in recommendations developed in relation to the proposed Yucca Mountain facility (NAS, 1995) is formulated in terms of health risk. By contrast, French (JORF, 1991) and some US regulations (USEPA, 1991; USNRC, 1999) are formulated in terms of dose. Swiss regulations (HSK/KSA, 1993) adopt a hybrid position, with a dose limit supplemented by a health risk limit for unlikely events and processes.

Many regulations and guidance documents suggest that an individual health risk target in the region of $10^{-6}$ per year and a constraint in the region of $10^{-5}$ per year have, at least to date, been interpreted internationally as providing a suitable basis for regulation. BIOMOVS II (SSI, 1996) noted that individual annual health risk levels in the range $10^{-6}$ to $10^{-5}$ are consistent with risk levels that society currently tolerates for large populations from a range of different hazards. However, higher individual risk exposures from non-radiological hazards, sometimes exceeding $10^{-4}$ per year (SSI, 1996), are often tolerated for populations of limited size.

### BII–2.3.2. Coherence considerations

A coherent overall approach to demonstrating compliance with radiation protection goals requires consideration of the relationship between the philosophy underlying the development of quantitative compliance criteria and that adopted in performing the exposure assessment. Furthermore, within the assessment itself there is a need for consistency between the description of hypothetical exposed groups and the assumptions underlying development of biosphere system descriptions.

A generally cautious assessment approach is dictated throughout ICRP guidance as a means to provide assurance that actual exposures are unlikely to be significantly underestimated. Hence, for example, in assessing future doses from normal exposure situations (e.g. in order to establish effluent discharge limits for new practices) it is normal to adopt conservative assumptions in respect of the location of the assumed receptor relative to potential future environmental concentrations. In the context of potential future releases from waste repositories, however, it may be that such an assumption would lead to a significant overestimate of actual radiological risks. An approach is therefore required that strikes a 'reasonable' note of caution without being over-conservative.

As far as published guidance is concerned, ICRP's interpretation of the term 'cautious, but reasonable' as applied to assumptions regarding future human behaviour is restricted to the recommendation that these should be 'realistic' and based on present knowledge (ICRP, 1985b; 1998b). Endless speculation regarding future human behaviour is therefore discouraged; nevertheless, this still leaves considerable room for interpretation in terms of what constitutes an adequate indicator of potential radiological impact (see Section BII–3.1, below).

Most national regulatory authorities have proposed radiological protection standards for waste disposal that are generally consistent with individual health risk levels tolerated for large populations from a range of different types of hazard. In addition, the regulatory guidance typically requires that these standards apply the calculated exposures for a critical group (i.e., a fairly small number of people), although at least one group, HSK/KSA in Switzerland, does link the risk limit to population size. Although ICRP suggests that both individual and population dose be kept as low as reasonably achievable (ICRP, 1998a; 1998b), the approach adopted in most national regulations could therefore be seen as demanding greater levels of protection than those applied to other sources of risk at the present day, because the limit on individual health risk is being applied to a small group, rather than the general population.

A conservative approach to the application of compliance standards, coupled with an overly-cautious assessment approach, could potentially lead to disproportionate attention and resources being allocated to the control of risks from waste disposal rather than those from other hazards (see also ICRP (1998a), paragraph (49)). Nevertheless, evidence from existing regulatory guidance seems to suggest that additional caution has been considered justifiable in the context of solid radioactive waste disposal.

In practice, the choices made will be need to be justified against the specific context within which the assessment is performed. It seems prudent to expect that demonstrating compliance with regulatory targets and/or constraints will typically involve multiple lines of reasoning, exploring a range of alternative exposure scenarios to build confidence in the results as a satisfactory quantitative basis for informing decision making. This does not necessarily mean that strict compliance with quantitative risk criteria needs to be demonstrated for all possible circumstances explored in the assessment. However, any assessment will need to be supported by sufficient justification to provide, for the particular context under consideration, satisfactory assurance that future individuals are afforded a level of protection consistent with that required today.

## BII–3. METHODS FOR IDENTIFYING EXPOSED GROUPS FOR SOLID RADIOACTIVE WASTE DISPOSAL ASSESSMENTS

### BII–3.1. INFLUENCES ON CHOICE OF APPROACH

The biosphere(s) and associated descriptions of human behaviour adopted for assessing system performance should provide a representative set of indicators of the potential radiological impact of the repository. When integrated with understanding arising from assessments of the behaviour of the disposal system as a whole, such indicators serve as an input to decisions regarding the acceptability of long-term system performance. The challenge, therefore, is to describe future human behaviour in such as way that, notwithstanding the speculative nature of various underlying assumptions, the results provide a sufficient degree of assurance regarding future levels of radiological protection.

Clearly, future human behaviour can be significantly affected by local or regional environmental factors, such as climate, topography and the availability of water and food. Moreover, human actions such as agricultural activity and civil engineering projects could also have a major impact on the environment into which future releases may occur. In the case of drilling and excavation, such actions may affect the timing, nature and extent of releases of radionuclides into the accessible environment. Thus, the desire for a coherent overall assessment dictates that the assumed socio-cultural and technological context is properly understood and defined as a prerequisite for characterising both the biosphere and future human behaviour.

#### BII–3.1.1. Reference to present-day behaviour

The range of possible future activities and behaviours that might be considered in representing the far future within an assessment is limited only by our imagination. Historical evidence shows that the potential for significant differences in future human behaviour (compared to the present day at any particular location) is large; moreover, such future behaviour is largely unknown and not open to predictive modelling. ICRP Publication 46 (ICRP, 1985b) seeks to provide a check on speculation by cautioning that 'realistic' assessments of radiological exposure, based on present knowledge, are essential if meaningful comparisons are to be made between different options and alternatives. This is especially the case if indicators of future radiological impact are to be meaningfully compared with exposures that are tolerated today.

Bearing in mind that the basic principle of providing assurance that future impacts are compatible with those tolerated today (IAEA, 1995), an appropriate starting point is to assign future individuals similar habits to those of the present-day populations against whom future projected risk levels will be compared. Apart from any other justification, such an approach would certainly help to address any local community concerns regarding the relevance of the assessment to their current location and practices. However, this does not necessarily mean that present-day behaviour at the site, or in the region of interest (e.g. in relation to the way that local environmental resources are presently exploited) will necessarily provide a sufficient basis for assessment. For example, if, as a result of climate change and related factors, future releases are likely to take place into an environment that is substantially different from that of today, it would be reasonable to expect that some analysis of alternatives - consistent with possible future environmental conditions - should be included. Indeed, this approach was suggested by a Swedish working group (SKI/SSI/SKB, 1989).

It is only for present-day releases that a reasonable measure of assurance can be given with respect to predictions of the detailed distributions of exposures among an exposed population (based on a distribution of location, age, habit, metabolism, and environmental factors). For potential exposures in the far future, any distribution of exposures adopted within an assessment can only be regarded as an assumption. Although such distributions could be generated for the far future by, for example, adopting present-day distributions in relation to behaviour, the endpoints of such an assessment would simply be one of many possible dose- or risk-based indicators of future disposal facility performance.

For some assessment contexts, therefore, representations of future human behaviour closely resembling present-day patterns of resource exploitation – perhaps even simulating a local community in the vicinity of the site – would be appropriate. Databases on local, regional or national dietary and other habits are also potentially relevant sources of information to an assessment. When justified by the assessment context, and if adequate data exist, it can also be acceptable to use data on historic land-use practices pertinent to the region, or on a wider spatial scale. Furthermore, where the assessment context dictates that future environmental change should be taken into account, it will be appropriate to represent human behaviour on the basis of present-day (or, if available, historical) practices from analogue locations with biosphere conditions similar to the altered biosphere.

### BII–3.1.2. Exposed group or individual behaviour?

The common use of limits or constraints expressed in terms of *individual* dose or risk may be taken to imply that it is necessary to define future *individual* behaviour, rather than future *group* or *societal* behaviour. However, this is not the intent of much of the existing guidance and national regulations. For example, according to ICRP's recommendations in relation to 'normal exposures' (ICRP, 1991), dose constraints should be applied to the mean dose among a collection of individuals forming a homogeneous group with respect to exposure from a given source. The aim of such an approach is to prevent decisions from being unduly influenced by the discovery of perhaps one or two individuals with extreme habits leading to exposure.

For many assessment contexts, then, it would appear both necessary and appropriate to compile assumed distributions of future behaviour into a limited set of behavioural groups. For cases where the definition of a 'critical' group is required, the aim should then be to address alternatives for the possible behaviour of a hypothetical 'Reasonably Maximally Exposed Individual' (RMEI), giving due regard to the need for adopting cautious, *but reasonable*, assumptions (ICRP, 1985b). This should not be taken to imply that the RMEI necessarily represents some separate, specific individual. Rather, it should be representative of the reasonable behaviour exhibited by members of a maximally exposed group of limited size.

From a practical standpoint, it may be noted that information related to the behaviour of individuals is often used to derive 'average' behaviour, or to provide an estimate of individual behaviour distribution. For example, survey data of individual habits (e.g. consumption of foodstuffs, location, use of local resources) is typically used to establish, quantitatively, the characteristics of a particular group for a safety assessment. The intent of the majority of existing guidance and regulations, including ICRP guidance, is consistent with this practice. This does not mean, however, that behaviour of a single individual from a survey can properly be used *in isolation*. Indeed, whereas the full set of results of a habit survey may be regarded as an indicator of an underlying distribution, the values adopted for assessment purposes should not be unduly influenced by the discovery of one or two individuals with extreme habits.

### BII–3.1.3. Physiological characteristics

Typically, in identifying critical groups for normal exposures to routine discharges from nuclear installations, standard 'reference' values of physiological parameters are adopted as part of the assessment basis. In principle, the same level of cautious, but reasonable assurance regarding protection would be provided by using similar generic data in the context of hypothetical exposures within a reference biosphere system assumed for the purposes of long-term assessment. However, a question remains regarding the extent to which different demographic, or other, groups with special physiological characteristics affecting their absorbed dose or health risk, need to be addressed.

According to the guidance given in ICRP Publication 43 (ICRP, 1985a), doses to critical groups may reasonably be expected to address age-dependent variations in metabolism, at least in terms of identifying representative (rather than extreme) exposures. The adoption of a 'cautious' approach in addressing exposures in the long-term future might therefore be anticipated to embrace children and infants as separate hypothetical exposed groups. Although not as large as that for adults, a significant body of biokinetic and dosimetric data for infants and children does exist, making a separate analysis for these subgroups possible. Dose coefficients are generally higher for children than for adults because (i) gut uptake factors are usually greater; and (ii) radionuclides that are retained in the body will tend to deliver a higher absorbed dose (energy per unit mass) to smaller body organs.

Yet, the particular characteristics of exposures resulting from solid radioactive waste disposal on land suggest age-dependent analyses may not be necessary. Long-term discharges from waste disposal facilities will tend to give rise to life-long, chronic exposures. Because individuals will spend most of their lives while exposed as adults, taking account of exposures during infancy and childhood will not necessarily increase the estimated lifetime doses or health risks by very much. For example, ICRP Publication 81 (ICRP, 1998b) suggests it could be assumed that radioactive contamination of the biosphere due to releases from the repository would remain relatively constant over periods considerably longer than the human life span. Publication 81 concludes it is reasonable to calculate the annual dose/risk averaged over the lifetime of the individuals, which means that it is not necessary to calculate doses to different age groups. In particular, it is suggested that the lifetime average annual dose can then be adequately represented by the annual dose/risk to an adult.

Part of the difficulty in deciding how to address the issue of whether or not to consider different age groups separately arises because radiological safety standards tend to be addressed in terms of annual limits or targets, whereas assessment modelling – particularly at long times into the future – inevitably invokes temporal averaging in the representation of events and processes. For example, rainfall may be represented not simply in terms of a monthly-averaged rate, but as a *long-term* monthly-averaged rate, based on mean values expected for a given climate over several decades. The biosphere system in which exposure occurs will therefore typically be represented within an assessment model such that environmental concentrations of radionuclides are determined only in terms of their long-term average values. This challenges the internal consistency associated with performing separate 'snap-shot' calculations of annual exposure for different age groups, rather than lifetime-average annual exposures.

Furthermore, from a practical standpoint, variations arising from differences in critical group behaviour may be significantly less than underlying uncertainties in dosimetry (Smith et al., 1997). For example, some aspects of the behaviour of children and infants (e.g. dietary intake of many foodstuffs) would give rise to rather less exposure than for adults, whereas others (e.g. consumption of milk, exposure to dirt) could be responsible for considerably more. It is difficult to be precise, but a range of up to a factor of five difference, or uncertainty, in annual exposures associated with age-dependent behaviour patterns seems reasonable for most exposure pathways. However, uncertainties in the relevant metabolic and biochemical models and parameters relating to internal dosimetry for children and infants in particular are far larger (with certain specific exceptions) than those associated with behaviour.

Nevertheless, for some assessment contexts, reassurance may need to be provided that children and infants, and other potentially sensitive groups, are adequately protected. This could be seen as being consistent with the overall aim of using multiple lines of reasoning to build confidence in quantitative assessments as a satisfactory quantitative basis for informed decision making. It is not clear if such matters are better addressed in establishing radiological protection standards for waste disposal or if they should be explicitly accounted for in the performance assessments themselves. In either case, the aim should be to determine whether or not differences in overall exposure for different demographic groups are small and, if necessary, to account for variabilities with an appropriate margin of caution.

### BII–3.1.4. Parameters relevant to the characterisation of human behaviour

Environmental modelling in post-closure performance assessment provides estimates of the concentrations of radionuclides in various components of the biosphere system.[6] The additional information necessary to evaluate radiological exposures, dose and risk can be divided into the following primary classes:

*(a) General description of the hypothetical exposed group(s)*

This description should be sufficient to form the basis for defining particular patterns of behaviour and should be consistent with underlying assumptions regarding the socioecomic structure of the wider community and the relationship of such communities to their environment. The level of detail required will depend on the specific approach taken in performing the calculation. Nevertheless, relevant information might include, for example: consideration of the environmental resources that are exploited by the community; and the different demographic groups to be considered in the assessment.

*(b) General description of activities leading to radiation exposure*

Relevant group- or age-specific activities to be considered include: eating and drinking; washing; type of work (including relevant sub-tasks linked to particular modes of exposure e.g. those activities that may be associated with enhanced ambient dust levels); recreation; sleeping.

*(c) Physiology*

Important factors contributing to physiological differences, and thereby potentially affecting radiological exposures, include age, sex and metabolic characteristics (breathing rate, exercise

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6 It must be remembered, however, that the environmental model should be developed with consideration of the influence the assumed society on the characteristics of the biosphere. Exposed group assumptions and biosphere definition should therefore be developed together to avoid inconsistency.

etc). These need to be specified for each hypothetical exposed group. Apart from their influence on dietary intake of different contaminated foodstuffs, such factors will also influence biokinetics (the retention of ingested radionuclides in tissue) and exposure geometries (i.e. tissue masses and their configuration with respect to radiation sources). In certain cases, internal exposures from radioisotopes of elements that are homeostatically controlled in the body (e.g. iodine, chlorine) may be influenced strongly by the assumed abundance of the natural counterpart or other chemically similar elements within the diet.

*(d) Location*

A description of the surroundings in which each activity defined in (b) is assumed to take place. In addition to general location considerations (e.g. agricultural or urban land), further qualification (e.g. indoor/outdoor) may be appropriate in order better to characterise factors such as dust levels or the degree of shielding from external irradiation.

*(e) Mode of exposure*

The principal modes of exposure relevant to radiological exposure assessment are ingestion, inhalation and external irradiation. It is generally considered that doses incurred via other modes of exposure (e.g. adhesion to skin and hair, transcutaneous transfer) will be relatively unimportant (SSI, 1996).

*(f) Rate/duration of exposure*

Relevant parameters correspond to the information necessary to quantify annual average exposures from each potential source. These include, for example: ingestion rates of different foodstuffs and (for inhalation and external exposures) occupancy times at different locations.

An example of applying the general guidance in (a) above to the identification of a 'cautious but reasonable' critical group, or RMEI is as follows. If it were assumed that the hypothetical 'most-exposed individual' was part of a community sharing resources collected from a wide area, exposures might be reduced through the mixing of local foodstuffs with resources from outside the immediate area of highest contamination. Whereas caution dictates that such causes of exposure 'dilution' should not be overstated, it is reasonable to expect that some consideration should be given to the size of the group 'at risk' from future discharges.

One justification for considering the likely 'dilution' in exposure associated with increasing the size of the group is the desire to provide a reasonable representation of the distribution of future behaviour in relation to the environment. It would be overly cautious to assume, for example, that virtually all the release takes place into an area the size of a family garden (e.g. an area of rather less than one hectare), and that the area is used as a family garden that provides 100% of the nutritional needs for the family. However, it would probably be considered reasonable to evaluate the exposure arising from that part of the release that affected such an area. Only when reasonable spatial distributions of both the release itself and human behaviour are considered can a reasonable estimate of the future impact of the waste disposal facility be provided. This is particularly important in comparing the results of an assessment with regulatory criteria; it is not necessarily reasonable to apply an individual risk limit on the order of individual risk levels tolerated for large numbers of people if the assessment is for a situation in which only a few people can be exposed (SSI, 1996).

### BII–3.1.5. Accounting for uncertainties

Past ICRP guidance (ICRP, 1993), and that of many national regulatory agencies, has implied that 'potential' radiological exposures are properly managed through controls on risk, taking account of the likelihood of exposure. Temporal and spatial uncertainties in the concentration profile of contamination emerging from a repository, evaluated using, for example, Monte Carlo simulations for alternative realisations of the performance of the disposal system, are often assumed to provide a suitable basis for determining the exposure probabilities. In each realisation the environmental contamination is described as a function of time; however, its characteristics (e.g. time of peak discharge to the biosphere, region of contamination, dominant radionuclides) may differ from one realisation to the next.

An important consideration in the probabilistic treatment of such uncertainties is the location of the assumed individuals in relation to the contaminated biosphere system (see, for example, the extended discussion in (NAS, 1995) where it is suggested that the location of individuals in the biosphere be generated stochastically for each Monte Carlo realisation). A balance needs to be reached between achieving an appropriate level of caution in the mathematical aggregation of risk contributions from different realisations and the basis on which the quantitative evaluation criteria themselves are defined, especially as the definition of the exposed groups may differ for each realisation (Thorne, 1989). Although cautious, it is not obvious how to interpret an individual 'risk'[7] that has been calculated on the basis of the average dose experienced via exposure to the highest environmental concentrations in each future realisation. Consequently, it becomes difficult to determine whether or not the safety goal (that future individuals are afforded a level of protection consistent with risks tolerated today) has been achieved.

The potential complexities of the interaction between exposed group definition and uncertainties in waste system performance are not addressed in detail within this document. They are nevertheless raised here as a key consideration in the appraisal of alternative approaches to identifying exposed groups for use in comparisons against regulatory benchmarks. Both deterministic and probabilistic approaches to defining future human behaviour as a basis for evaluating radiological impact will have their place in comparisons against criteria, by helping to develop the required level of assurance to inform decision making.

## BII–3.2. PRINCIPAL OPTIONS

Decisions regarding the hypothetical exposed groups relevant to a given assessment context – their numbers, diet and other behaviour – cannot be considered independently of the assessment-specific biosphere system description. The 'process system' represented in the biosphere assessment model will depend on underlying assumptions related to socio-economic and cultural context that determine human interaction with the biosphere. The assumed scale and manner of exploitation of biosphere resources by a hypothetical local community, as guided by the assessment context, is fundamental to any evaluation of potential radiological impact. The overall aim is to achieve a measure of coherence, both within various

[7] 'Risk' can be used in the sense of including potential exposures, where probabilities must be assigned to alternate scenarios giving rise to different levels of exposure. This is different from 'health risk', which is often considered to include only the probability that an individual will develop a health effect *from a 'certain' fixed dose*. 'Risk', as used here, can include both concepts (Watkins and Kessler 1998).

elements of the calculation of radiological impact and set against the underlying assumptions on which radiological criteria are themselves determined.

Broadly speaking, there are two main alternative strategies for identifying and describing the assumed behaviour of members of hypothetical exposed groups to provide quantitative estimates of human impact due to potential releases in the long-term future. In what follows, these are identified as the a priori and the a posteriori approaches. Some detailed considerations in relation to the implementation of these two alternative approaches are addressed in Sections BII–3.2.1 and BII–3.2.2. In practice, it seems likely that the relative strengths of the different approaches will depend on the context in which the assessment is performed. A comparison of the possible advantages and disadvantages of each method is therefore presented in Section BII–3.2.3.

### BII–3.2.1. 'A Priori' identification

In the *a priori* approach, the assumed characteristics and habits of the critical group(s) are fixed prior to performing the exposure calculation, and this then serves as a representative indicator of the maximum potential exposure. The *a priori* approach takes as a premise the fact that any definition of human behaviour in the long term is essentially speculative, but that scientifically-informed reasoning (e.g. in relation to the potential importance of different exposure pathways for different radionuclides) can be used to make sensible judgments regarding the hypotheses appropriate to performing an exposure assessment. It also emphasises the importance of seeking to achieve coherence between assumptions underlying the identification and definition of biosphere systems representative of the long-term future and those involved in describing human behaviour.

#### *BII–3.2.1.1. Past guidance – 'subsistence' farming*

The UK National Radiological Protection Board (NRPB, 1992) and the (IAEA, 1999) both suggest that the habits of the critical group should be representative of 'typical' subsistence farmers. This is based on their assumption that subsistence farmers make a (reasonable) maximum use of local environmental resources; for example, exclusive reliance of local water supplies for all uses – including agricultural purposes – will tend to enhance radiological exposures compared with situations where more diverse sources are exploited. The deliberate recycling of materials and nutrients would also be expected to enhance the accumulation of radionuclides in environmental media and thereby maximise exposures. Thus, such farmers might be possibly expected to have the highest exposure risk.

It is not immediately evident, however, that such a group necessarily provides a fully sufficient basis for ensuring consistency of protection with that afforded by today's radiological protection practices, or that it would always be associated with the highest potential risks. Furthermore, there is little information available concerning biosphere systems and human behaviour relating to 'true' subsistence farming methods. Here 'true' subsistence farming refers to farming in which only *local* resources are available to the farmer. This would preclude the use of modern farming practices that make use of many 'imported' resources (e.g. modern farm machinery produced in factories, fuel, fertilizers). 'True' subsistence farming would have to involve, for example, use of farm animals for ploughing or composting practices as the sole source of fertilizer.

Whereas descriptions of human behaviour typical of such communities may be warranted as part of the assessment if, for example, a cautious assessment philosophy is prescribed, it seems advisable to explore alternative possibilities as a contribution to multiple lines of reasoning, particularly when comparisons are being made with regulatory benchmarks. Consideration of a broader range of alternatives would address concerns regarding the relevance of subsistence farming to present-day behaviour in the vicinity of most existing or planned radioactive waste disposal sites – or indeed to candidate analogue biosphere systems representative of the long-term future. A more general approach is therefore required, consistent with underlying assessment assumptions regarding the level of technological development and socioeconomic structures.

*BII–3.2.1.2. Identifying exposed groups based on resource exploitation strategies*

For present-day effluent discharges from nuclear installations, potential critical groups are identified by considering the different ways in which members of the local population can be exposed to radioactivity from the local environment. Habit surveys are conducted on the dietary characteristics of the local community and how it exploits local environmental resources.

By analogy, *a priori* descriptions of human behaviour characteristics can be made that relate their use of resources in the biosphere to long-term indicators of radiological impact. Given the convention that extremes of behaviour do not need to be considered in radiological assessments in order to demonstrate adequate protection of individuals, emphasis can justifiably be placed on units of resource exploitation that are sustainable over several generations in environmental systems representative of the future biosphere at the location of interest. For example, for a subgroup composed of wild game hunters and eaters, it should be assumed that the hunting rate is limited so as to avoid permanent depletion of the stocks of available wild game. The identification of different modes of resource exploitation within the local biosphere is a key step in providing a self-consistent basis for describing the interaction between human communities and their environment.

In the *a priori* approach, the primary elements for identifying and defining relevant human habits are units of resource exploitation representatative of particular subgroups within the local community. The way and the efficiency with which resources from the local biosphere system are exploited will depend on basic (i.e. assessment context) assumptions regarding socioeconomic structures, as well as the level of technological development. Relevant data for characterising the relationship of individual members of resource exploitation units to their environment might include:

- a description of the group (e.g. the group of consumers of a particular local foodstuff);
- the number of people associated with a typical unit (e.g. a farmer and his family);
- the area over which resources are exploited by the unit.

*BII–3.2.1.3. Dietary and physiological characteristics of exposed groups*

For each type of resource exploitation unit, a group of individuals can be identified (based on available data) who make maximum reasonable usage of the resources available and who would therefore receive the highest exposures from any contamination in that particular environment. A cautious, but reasonable, approach to identifying hypothetical exposed groups would then be to characterise individual habits on the basis of the information describing the actual behaviour of analogue communities forming sustainable units of resource exploitation in comparable biosphere systems. Thus, the analogue communities must be ones that exist today, or existed in the past, for which adequate data characterising a reasonable range of community behaviour are available. Here 'reasonable range' means that data related to the characteristics described in paragraph (59) are available for subgroups within the analogue community that make maximum reasonable use of the local biosphere resources.

If detailed quantitative information on present-day or historical analogue communities is not available, it may be necessary to revert to more general descriptions of behaviour, based on prevailing patterns of resource exploitation in such communities. Thus, for example, an agricultural community could be considered to include a population subgroup that consumes 'above-average' amounts of locally-produced foods. Different emphases would be obtained by focusing on say, beef farming or market gardening as alternative patterns of resource exploitation. Alternatively, a coastal community might include local fishermen, with different groups emphasising different marine pathways, such as fish and crustacea or molluscs.

As far as the consumption of specific dietary items is concerned, it is often assumed that, provided the sample is sufficiently large, the top 5% of a distribution may be taken as representative of a critical consumer group (Hunt et al., 1982; Tscherlovits and Beninson, 1983). Established databases suggest that the 95$^{th}$ or 97.5$^{th}$ percentiles of consumption rate for many staple foods tend to exceed the mean values by approximately a factor of three. Hence for any given population, the 'safety criterion' (in the context of routine discharges) tends to be set at three times average behaviour (MAFF, 1996; 1997). Such an approach is also in line with ICRP guidance. Therefore, using approximately the 95$^{th}$ to 97.5$^{th}$ percentile of behaviour to define a 'critical' consumer group, rather than either a higher or lower percentile, is considered to represent a cautious, but reasonable assumption.

Generalised data sources, based on national surveys, can provide a useful source of information, particularly in terms of addressing a diverse range of potential behaviour. However, small communities with specific patterns of behaviour are often not very well represented in national, or even regional, statistics. Care therefore needs to be taken in basing assumed behaviour on such sources, particularly for more unusual habits associated with specific types of biosphere system. Detailed implications of guidance on the definition of critical groups from relevant habit survey data has been explored in various studies relating to present-day discharges (Hunt et al., 1982; Robinson and Simmonds, 1992; MAFF, 1996; 1997). Local habit surveys – if necessary at analogue locations – are particularly relevant where environmental conditions are such that the diets and other habits of local communities are likely to differ significantly from national and regional patterns.

Consideration of the way in which biosphere system resources may be exploited provides a basis for identifying groups of people that are exposed to contaminants via the same environmental pathway(s). Nevertheless, such a group cannot necessarily be considered homogeneous with respect to radiation exposure, because any one individual may, and usually does exploit more than one resource. Furthermore, their individual physiological characteristics will determine both their degree of exposure and the radiation doses that arise as a consequence.

### BII–3.2.2. 'A Posteriori' identification

The *a posteriori* approach to identifying exposed groups adopts the premise that it is possible to determine which particular combination of characteristics of human behaviour would cause an individual to be among those incurring a given exposure range (e.g. among the highest exposures) only after each pathway has been assessed quantitatively, having regard to the specific mix of radionuclides present in the discharge to the biosphere at the time of interest. Hence, rather than adopting fixed prior assumptions concerning the characteristics of human behaviour in relation to the local environment, mathematical sampling methods are used to 'explore' various possible contributions to exposure. The aim is to address a comprehensive set of exposure pathways that might potentially be relevant within the assumed biosphere system, selecting a combination that, while not being unrealistic, corresponds to the average exposure, critical group, or maximally exposed individual, as appropriate.

The *a posteriori* approach applied to identifying the maximally exposed group incorporates the following basic steps:

(a) Identify a general set of potential exposure pathways, accounting for the specifics of the assumed biosphere system(s) and taking account of the overall assessment context. Particular attention needs to be given to basic assumptions regarding socio-economic structures and level of technological development. The identification needs to be performed in conjunction with the biosphere system description(s) in order to ensure that reasonable consistency is achieved between the assumed pathways and the biosphere(s)[8]. Tools such as the Interaction Matrix method developed in BIOMOVS II (SSI, 1996), can be used to accomplish this.

(b) Develop exposure models to assess the dose (or health risk) arising from 'unit' exposure to each pathway individually (e.g. consumption of unit mass of a given foodstuff, inhalation of unit mass of dust per year, external irradiation from a given source (such as via bathing/swimming) per year), assuming unit concentration of each radionuclide in the media of interest.

(c) Given an assumed release of radionuclides to the biosphere, calculate the total dose or health risk due to unit exposure via each pathway.

(d) Combine the exposures arising from different pathways according to samples taken from distributions of potential behaviour. For example, national food survey statistics (truncated, where necessary, to avoid excessive pessimism by simulating behaviour at the extreme tails of the distribution) would provide relevant distributions of consumption rate for different foodstuffs. Overall exposures would be constrained by setting upper and lower limits to total consumption, in terms of (for example) calorific intake, water intake, trace mineral requirements, fat and protein requirements, consistent with the underlying biosphere system description and socio-cultural assumptions (e.g. see Kessler and Klos (1998)). For inhalation and external exposure pathways, sampling might be based on the assumed occupancy at different locations, based on the constraint of the total number of hours per year and basic requirements for time spent eating, working, sleeping etc.

(e) Identify the combination of exposure pathways that gives rise to the highest dose or health risk for the assumed release to the biosphere.

The behavioural characteristics of the 'most exposed' group chosen according to this method may vary from one realisation of the future releases from the disposal facility to the next. The

[8] While some PA work has implied this is not a requirement, consistency is always to be valued. For example, it would not be consistent to define a biosphere containing land farmed using modern agricultural practices in conjunction with human characteristics representative of hunter-gatherers. In some regulatory regimes, prescriptive guidance may exist regarding specification of human habits relevant to compliance assessments. Convergence of views on the performance and safety of disposal systems is recognised as an important goal, even though different approaches to reaching such a conclusion may be used (IAEA 1997).

group would also be likely to vary temporally within a given realisation. For example, if in one realisation the release from the geosphere into the biosphere is dominated by Tc-99 and occurs at one particular geosphere/biosphere interface (transfer into a river) then the dominant exposure pathway may be consumption of fruit irrigated by river water. If, in another realisation, exposure at the same time were dominated by plutonium species and their daughters (as a result of groundwater being abstracted for irrigation of soil), then the dominant pathway may be inhalation of contaminated dust.

The *a posteriori* approach helps to identify pathways (or potential combinations of pathways) that might not otherwise have been addressed in an *a priori* definition of exposed groups. However, there may be conceptual difficulties in interpreting the meaning of aggregated risk (or expectation value of exposure) over different scenarios.

### BII–3.2.3. Comparison of alternative approaches

Neither a strict *a priori* approach, nor rigorous adherence to *a posteriori* reasoning, is considered appropriate for assessment purposes. The range of potential exposure pathways accommodated within the biosphere model needs to be sufficiently broad to provide assurance that no substantive issues are ignored. However, it also needs to be recognised that no calculation, however detailed, will necessarily be able to provide absolute assurance that precise quantitative criteria will be met for every possible eventuality. Some form of intermediate approach is therefore required.

An investigation of the significance of alternative assumptions regarding human behaviour is therefore indicated, but speculation needs to be constrained by seeking to adopt a ‘realistic’ approach to evaluating potential radiological exposure, based on present-day knowledge of behaviour in analogue biosphere systems. Such considerations, combined with scientific understanding regarding the potential importance of different exposure pathways and the results of iterative assessments based on both approaches, as well as the underlying assessment context, ultimately underpin judgements made in relation to the identification of relevant exposed groups.

As an example of combining both approaches, the behaviour and characteristics of several hypothetical exposed groups – candidate critical groups - could be specified, consistent with the typical patterns of resource exploitation in different biosphere systems. Having evaluated total exposures for each candidate critical group, the ‘most exposed’ of these pre-defined groups would then constitute the ‘critical’ group for comparison with safety criteria. Another example involves restricting the analysis to a limited number of ‘significant’ pathways, and excluding potential combinations of diets, habits, and exposure pathways that could otherwise be considered ‘extreme’. Such an approach would, however, necessarily invoke some *a priori* knowledge or assumptions related to the significance of specific exposure pathways, either in terms of their radiological importance, or their relevance to decision making.

Both the *a priori* and the *a posteriori* approaches have advantages and disadvantages. The advantages of the *a priori* approach include: consistency in the characterisation of hypothetical exposed groups for all possible realisations involving the biosphere system of interest; and an ability to address explicit patterns of behaviour and/or resource exploitation that can be related to present-day experience (including, if desired or required, the present-day local community in the vicinity of the discharge). The fact that the definition of the exposed groups is related to prior experience rather than being defined by a mathematical procedure means that the implications of the results may perhaps be more readily understood. In terms of coherence in presenting the overall results of a performance assessment, it is also relatively straightforward to aggregate the exposures from different realisations of the future performance of the disposal system for an individual member of a given exposed group at a particular time/location[9]. However, the approach is handicapped by the fact that any prior choice of 'representative' behaviours, although far from random, is essentially arbitrary and cannot be demonstrated to provide a robust estimate of the maximum potential exposure. It will therefore usually be appropriate to make separate calculations over a range of possible groups and exposure circumstances.

The advantages of the *a posteriori* approach lie in the fact that it makes no pre-judgment of the particular combination of exposure pathways leading to the highest exposure. The use of a suitably constrained mathematical sampling technique can serve to identify, with some assurance, group behaviour consistent with the concept of a 'reasonably maximally exposed individual' (RMEI). Reason is preserved by not allowing unrealistic combinations of exposure pathways (e.g. through constraints on dietary intake) and restricting the sampling of potential behaviour within truncated versions of population distributions.

There are also a few disadvantages of the *a posteriori* approach. Because no explicit reference is made to present-day behaviour in analogue environments, care needs to be taken in defining the ranges of possible exposure to reflect those of communities typical of the assumed assessment biosphere system. In addition, problems of consistency may arise if it is desired to aggregate the doses (or risks) to exposed groups identified for the separate pathways from each of the different realisations of the future performance of the disposal system. If the RMEI differs between realisations, which is likely, the aggregate exposure will clearly represent an overestimate of the risk incurred by any specific individual. On the other hand, this disadvantage can be overcome by modifying the procedure of the *a posteriori* approach defined above. Instead of identifying behaviour that maximises total exposure over each pathway *prior* to aggregation (leading to a variety of exposed group characteristics when aggregated), a single set of behavioural characteristics can be identified that maximises the exposure for the aggregated case. A new step would therefore be inserted following step (c), as follows:

(c') Repeat step (c) for each realisation of the assumed release to the biosphere and then aggregate the unit dose or risk estimates across all the realisations. Then proceed with steps (d) and (e) for the aggregated, unit exposures. This modified approach fixes all locations, ages, metabolisms etc. for the suite of 'individuals' for whom exposures will be calculated for each separate realisation, so that separate individuals can be tracked through all realisations and consistency is maintained for each case. The 'individual' with the highest aggregated dose or health risk is then the RMEI.

Overall, it is considered that a combination of the two approaches could be used to establish the final exposed group definition(s). For example, consideration of a wider range of potential pathways (i.e. *a posteriori* approach) might initially be used to eliminate exposure pathways of negligible radiological significance from further consideration. This would then provide guidance for the selection of a small set of fixed (i.e. *a priori*) exposed groups (candidate critical groups), with reasonable confidence that the identified group(s) were sufficiently

9 Here, it is important to remember that the exposure for any single individual (with pre-defined habits, age, location, metabolism, etc.) may vary greatly from realisation to realisation in a probabilistic assessment. Nevertheless, it is possible to identify the single 'maximally exposed group' from the different candidates defined *a priori*, based on the aggregated exposures across all the realizations.

representative to provide adequate assurance of the protection of future communities. This is the approach that has been followed for the BIOMASS Example Reference Biospheres.

## BII–4. SUMMARY OF MAIN ISSUES AND GUIDANCE

The purpose of this document has been to provide information and guidance to aid the practical identification and characterisation of exposed groups to be considered in assessments of the long-term radiological impact of solid radioactive waste disposal. Particular attention has been paid to issues related to the uncertainties and practicalities associated with quantifying future human behaviour relevant to such an assessment. The document recognises that, because future human behaviour is largely unknown, it is necessary to make a range of assumptions and hypotheses, and to demonstrate that the identified groups provide a satisfactory basis for radiological assessment. Within the BIOMASS Methodology, the characterisation of exposure pathways and exposure groups to be considered in the assessment is seen as being critically dependent on the overall context within which the assessment is performed.

Because of its common usage in a variety of international guidance and national regulations, many considerations and guidance related to identifying ‘critical groups’ have been included here. In seeking to constrain the potential range of ‘critical group’ habits (such as consumption of a specific foodstuff), extremes of individual behaviour that would be overly cautious, and therefore outside the range of what might be found in a broader community from which the critical group is identified, should be avoided. Established databases suggest that, provided the sampled population is sufficiently large, the top 5% of a distribution may be taken as representative of a critical consumer group for a particular foodstuff. Hence, the 95$^{th}$ or 97.5$^{th}$ percentile of consumption rate for staple foods (depending on the source and structure of the actual distribution) is generally thought to represent a suitable upper bound for any given exposure pathway.

Nevertheless, it is not possible to identify a single group that can clearly be shown to be representative of those individuals in the population expected to incur the highest dose or risk in all circumstances. Furthermore, it is not necessarily reasonable to apply an individual risk limit comparable to levels of individual risk that society tolerates for large numbers of people (usually rather low) if the assessment is for a situation in which only a few people can be exposed (in which case society generally tolerates somewhat higher individual risks).

No single method of characterising human behaviour in long-term exposure assessments can be recommended for all circumstances. However, endless speculation into potential future human activities provides no further assurance regarding the adequacy of the chosen indicator of radiological impact. Approaches are required that use ‘cautious, but reasonable’ assumptions, based on present-day knowledge, to provide satisfactory assurance that the predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today, or at least that the predictions are appropriate for use in present-day decision making. This involves the characterisation of hypothetical ‘exposed groups’, and the use of multiple lines of reasoning to compare the results obtained using different approaches with regulatory criteria.

A prime requirement is therefore to identify and describe the assumptions underlying the calculations of radiological exposure. This requires that premises relating to the socioeconomic, cultural and technological context, within which future biosphere systems and human behaviour are identified and characterised, are clearly defined[10]. These factors, combined with scientific understanding regarding the potential importance of different exposure pathways, underpin the identification of relevant exposed groups. The general classes of information required to fully characterise hypothetical exposed groups are as follows:

- *General description of activities leading to radiation exposure* – relevant activities to be considered include: eating and drinking; washing; type of work (including activities linked to biosphere resource exploitatation); recreation; sleeping.
- *Physiological characteristics* – factors contributing to physiological differences include age, sex and metabolic characteristics. Apart from their influence on the potential intake of contaminated materials, such factors will also influence biokinetics and exposure geometries.
- *Location* – a description of the environmental surroundings occupied by members of the exposed group. In addition to general location considerations (e.g. agricultural or urban land), further qualification (e.g. indoor/outdoor) may be appropriate in order better to characterise factors such as dust levels or the degree of shielding from external irradiation.
- *Mode of exposure* – the principal modes of exposure relevant to radiological exposure assessment are ingestion, inhalation and external irradiation.
- *Rate and duration of exposure* – relevant parameters correspond to the information necessary to quantify annual average exposures from each potential source; for example: ingestion rates of different foodstuffs and occupancy times at different locations.

Two approaches have been identified for the definition of specific exposed groups, particularly the critical group: the *a priori* method and the *a posteriori* method. There are advantages and disadvantages to using either method, and it is recommended that a combination of the two should be used. The overall aim should be to achieve a measure of consistency, both within various elements of the calculation of radiological impact and between the calculational approach and methods used to determine acceptance criteria.

Although dose (or risk) constraints or limits are commonly expressed in terms of *individual* dose (or risk), such constraints/limits are usually intended to apply to a representative member of the exposed *group*. In practice, however, information related to the behaviour of individuals is often used to derive 'average' group behaviour, or to provide an estimate of individual behaviour distribution. For example, survey data of individual habits (e.g. consumption of foodstuffs, location, use of local resources) are typically used to quantify the characteristics of a particular exposed group for a safety assessment. Most existing guidance and regulations, including ICRP guidance, is consistent with this practice.

It is not possible to make definitive recommendations regarding data sources for human behaviour – in general terms, the best use should be made of available data corresponding to identified analogue communities and biosphere systems. Although generalised data, based on national statistics, can provide a useful source of information on a wide range of behaviour patterns, small communities with specific diets or patterns of behaviour are often not adequately represented in national food statistics. Care therefore needs to be taken in basing

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[10] The establishment of the assumed socio-cultural context is also recognised to be mutually dependent on the future biosystem, in so far as coherence needs to be demonstrated between the two.

assumed behaviour on such sources, particularly for more unusual habits. Local habit surveys – if necessary at analogue locations – are particularly relevant where environmental conditions are such that the diets and habits of local communities are likely to differ significantly from national or regional patterns.

The biosphere system in which exposure occurs will usually be represented within an assessment model such that environmental concentrations of radionuclides can only be determined as long-term average values (in view of general uncertainties and small scale variabilities that are difficult to model). This challenges the internal consistency associated with performing separate 'snap-shot' calculations of annual exposure for different age groups, rather than lifetime-average annual exposures. For these and other reasons, it may be inappropriate to make separate calculations for the exposure of infants, children and other demographic groups that may be at special risk. Nevertheless, for certain assessment contexts, it will be consistent with the overall aim of providing multiple lines of reasoning to give some reassurance that potentially sensitive groups within the population are adequately protected.

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# ANNEX BIII
# ISSUES ASSOCIATED WITH THE DERIVATION AND APPLICATION OF DATA FOR ASSESSMENT MODELS

## BIII–1. INTRODUCTION

The construction of databases for models and the interpretation of data, including the definition of uncertainty bounds on parameter values, have been shown through intercomparison exercises such as BIOMOVS II (SSI, 1993; 1996) to be particularly important factors contributing to differences in model results and interpretations. Whereas the derivation of assessment-specific parameters from a wider database of basic biosphere information is a general problem in environmental modelling, it is a particularly important consideration in the context of long-term biosphere assessments because of the high degree of variability of biosphere characteristics through time, and the high level of discrepancy between current performance assessment models and reality.

No general guidance on such problems was developed during BIOMOVS II, although some specific questions were identified as needing further consideration. It was therefore proposed that a set of guiding principles should be developed within BIOMASS Theme 1.

Past experience has demonstrated that there is an extensive list of issues, or at least constraints, attached to the overall management of data:

- the strong relationship between models and data: each aspect influences the other, and they should be considered in parallel when developing models and determining parameter values;
- data are categorised: they belong to main families which are different, thus data should be treated differently when gathered and processed according to their data type;
- there are various sources of data coming from different scientific disciplines and these sources have often been produced for different purposes;
- consequently, the available data may or may not be suitable for a given assessment context, and one should react accordingly;
- the selection and representation of data in order to determine a parameter value is not straightforward, even if data are available;
- there are numerous sources of uncertainty affecting the production of data and the determination of parameter values.

Nonetheless, awareness of these issues has existed since the beginning of the development of assessment models, and different approaches have been used for controlling them:

- the direct recourse to expert judgement, sometimes searching for a certain level of consensus, but without following a formal elicitation process;
- the identification of the most important parameters and the appraisal of the consequence of the uncertainty in their determination through the performance of sensitivity and uncertainty analyses after undertaking assessment calculations;
- the performance of elicitation exercises combining qualitative and quantitative arguments organised through structured approaches before undertaking assessment calculations.

However, when focusing on the biosphere component of the safety assessment of waste disposal, one faces the problem that there is only partial information in the literature, in the sense that the biosphere component has not usually been addressed in a comprehensive way, thus leading to the omission of some specific factors, such as variability of the data types and the heterogeneity in data availability.

The purpose of this Annex is to describe the development of a protocol for the derivation of data that should take into account the biosphere assessment specificities, the major issues associated with the management of data, and the constraints linked to the relationships with the other components of the BIOMASS Methodology. The document is composed of three Sections:

- Section BIII–2 reviews the issues associated with the derivation and application of data for assessment models;
- Section BIII–3 formalises a protocol for the derivation of data, and illustrates its applicability by the performance of several illustrative examples;
- Section BIII–4 identifies particular issues arising from connections between other components of the BIOMASS Methodology and the "Data management" component.

## BIII–2. ISSUES ASSOCIATED WITH THE DERIVATION AND APPLICATION OF DATA FOR ASSESSMENT MODELS

### BIII–2.1. THE RELATIONSHIPS BETWEEN MODELS AND DATA

Since real ecological (biosphere) systems are generally observed as being complex, any model addressing an environmental issue is biased *a priori* by the way in which its relevant components (e.g. FEPs) were selected beforehand. Indeed, such models and their associated assumptions are, even if not explicitly stated, (over-) simplified versions of reality, and are essentially determined by the problem in focus when they are constructed, i.e. the context attached to their potential and actual use (Jorgensen, 1994).

Nonetheless, this simplification of reality is not a mere question of "apologetics": it is necessary to make the overall modelling management easier, especially with regard to the handling of mechanistic models, for which it is often difficult to attach a high level of confidence. It is important to understand this issue, for the level of simplification allowed in the model will steer the criteria for selecting parameter values (conservative, average, upper-bound etc.).

Therefore, it is necessary, from the very beginning, to characterise what kind of model and what data are to be considered under the topic, i.e. for a given assessment context. In the realm of performance assessment, it is likely that these models would certainly be more akin to so-called mathematical models, rather than pure experiment-focused empirical models, since performance assessment models usually focus on safety/protection (i.e. bounding values) and deal with time frames that are not accessible to the experimental investigation.

As a consequence, but without going too deeply into the details in the current document, it is interesting to address the implicitly accepted gap, that has been developing between "empiricists" and "modellers" for the past 30 years. Indeed, it appears that the emphasis has changed from a first loop "observation → hypothesis → prediction → experimentation →

observation...” (I), to a second loop: “assumptions → mathematical modelling → results → modifications → assumptions...” (II) (Grimm, 1994).
Any similarity between loops (I) and (II) is only superficial since there is no direct reference to natural science in loop (II). Many current models applied to performance assessment now often make no claim of producing testable predictions: they produce hypotheses, concepts and general assertions but work on their own, supported to some extent by an inner momentum, sometimes acknowledged and controlled, sometimes overlooked. It is expected, however, that sub-models should be testable. It could be assumed then that if testability is granted for key components of a given model, the aggregation of sub-models also would be testable to some extent. Following such an assumption, the existence of the two different loops (I) and (II) could be scientifically justified if it is established that there are clear connections between them (e.g. “validation” by component): then, their qualitative difference cannot be said to be just a matter of a lack of data. Another consequence is that it may not be relevant to speak about a necessity to “validate” assessment models: even if performance assessment models are usually disconnected from reality in order to fulfil the requirements of their task (*i.e.* the notion of “fitness for purpose”), there should be a way to re-connect them within the overall process of models and data management (e.g. see Figure BIII–1).

In short, the abstractness of models (“to sacrifice details for generality”), which has apparently developed at the expense of testability, could be justified as being an asset in the realm of performance assessment, but its associated limitations should be clearly stated as a preliminary condition of consistency.

In particular, if the models are to be useful intellectual tools, at least they should be understandable. This means that the associated data should also be manageable and understandable, to ensure the existence of mechanisms for preventing the tendency for the model to go too far astray from reality without any control on the drift.

For example, it could be useful to increase the number of parameters in a model without any direct benefit expected for the quality of calculations in term of numerical accuracy, but with the rationale of keeping a certain level of quality concerning physical description (conceptual or phenomenological modelling). On the other hand, if the phenomena underlying a process are not well understood, mechanistic modelling may sometimes be rejected in favour of numerical approximations. The issue at stake is the eventual understanding of the modelling target in each case.

The control and limitation of the discrepancy between model and reality could be called robustness. It is a quality that alleviates the consequences of the weakness of data determination on the assessment end-point.

Another argument associated with simplification is that, in assessments, the performer needs a solution (i.e. actual numbers), whatever the availability of data: in such a case, simplification helps in performing the calculations.

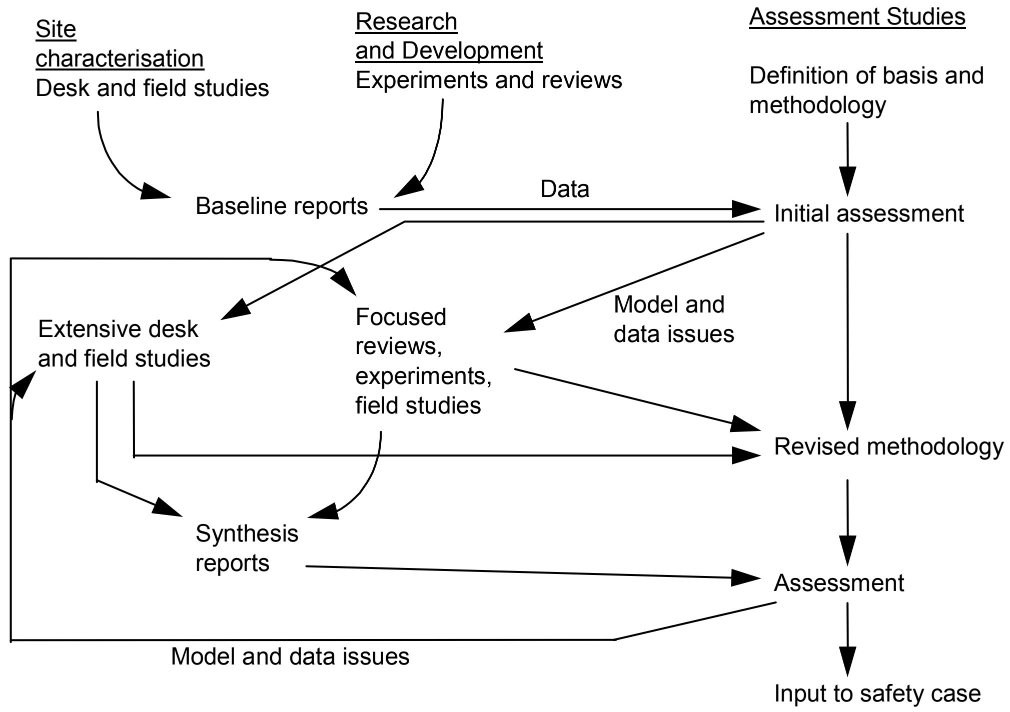



*FIG. BIII–1. Relationship between data use in assessments and data acquisition activities, taking account also of model and methodological developments.*

## BIII–2.2. THE CATEGORISATION OF DATA

The question of the nature of data with respect to the perception, analysis and treatment by human beings, is one of the leading aspects of epistemology (Russell, 1913), if not its sole purpose. An extensive discussion about this issue is easily found in the literature, but a brief discussion concerning the generic nature of data (ontology) in the current context is an interesting introduction to Section BIII–2.6 concerning uncertainties, particularly in order to understand that the notion of data is neither totally objective nor defined in a single way.

More practically, because of the large quantity of parameters usually encountered when performing biosphere calculations (SSI, 1996), experience indicates that it is sensible to try to cluster parameters according to some of their features. The most obvious partition is certainly that which separates the data depending on the radionuclide type (e.g. transfer factors) from those that are not radionuclide-specific. Its usefulness lies in the fact that the amount of information available for estimating the radionuclide-specific data is not equivalent for each of the radionuclides usually considered in a performance assessment.

Less intuitively and more practically, in considering the requirements for data management within the framework of actual integrated assessments, it has previously been found useful to identify the various types of data that were used in assessments according to broader categories. In a Nirex study (Nirex, 1994), the principal data types were specified as follows:

— *Topographical and geological maps*

  Used to identify hydrogeological units for groundwater flow and gas migration modelling.

— *Field and experimental data*

Data obtained from field sampling or experimental research. Hydrogeological and geochemical information, such as rock properties, detailed geological cross sections, groundwater compositions etc. Element solubility and sorption parameters for both the near- and far-field barriers in the repository system. Steel corrosion rate etc.

— *Literature data*

Radionuclide half-lives. Various biosphere data such as animal stocking densities, food consumption rates etc.

— *Design/inventory data*

Vault geometry and dimensions. Waste masses. Radionuclide inventory etc.

— *Data from formal elicitation*

Single values or probability density functions (pdfs) for hydrogeological parameters, element sorption parameters, cellulose dissolution rate etc.

— *Data derived from expert opinion/judgement*

Any data values required for particular conditions that are not covered by literature, experiment, or formal elicitation.

— *Data generated from other computer programs*

Nominal groundwater transit times, path length, specific discharge, gas generation rates, radionuclide chemical behaviour etc.

However, in the realm of biosphere assessment, it appears more logical to pursue the classification of parameters according to other types of categories such as (derived and adapted from (IAEA, 1989)):

— release characteristics: including the type of release, the radionuclide spectrum and the physical and chemical characteristics which are linked to them; they are usually provided in the assessment context;
— the parameters that influence, or are related to, the transport and accumulation in the biosphere components; they comprise the main set of parameters to be handled in a data protocol (see Section BIII–3);
— the exposure related parameters (living habits, consumption patterns, health status etc.) which are also included in a data protocol (see Section BIII–3);
— the dosimetric data, which are usually provided in internationally accepted references such as the ICRP publications, insofar as they are also accepted averages consistent with the expected calculation end-points.

Other data categorisation schemes may be worth considering, depending for example on the potential data availability and consistency which could drive a structured approach (see Section BIII–3), or the relative importance of parameters to the level of confidence attached to modelling, determined from the output of sensitivity analyses (see Section BIII–2.7).

Some parameters are important for their role in calibrating (tuning) the models, to ensure fundamental aspects such as mass balance (Jorgensen, 1994).

## BIII–2.3. SOURCES OF DATA

An extensive discussion about data sources, reliability, applicability and traceability is developed in reference (Coughtrey, 1992), from which the following main ideas were extracted.

There exists a vast literature dealing with the determination of parameter values, ranging from scientific articles in reviews to unpublished technical reports, through to internationally accepted generic databases. From them, it is possible to derive only poorly specified generic values or to derive relatively accurate values from very well described experiments (e.g. database of soil to plant transfer factors). Sources of information for deriving non radionuclide-specific data are usually different from those used for determining radionuclide-specific data.

The main data sources quoted are: studies following nuclear weapon tests; the studies on routine releases from facilities of the nuclear fuel cycle; studies conducted near shallow-land and marine disposal sites; studies following accidental events; studies on naturally occurring radionuclides and stable elements; and reports about experiments performed under controlled conditions.

The reliability of the derived values is quoted as a matter of subjective opinion depending on questions raised during parameter derivation. Such questions are necessary to address the global modelling uncertainty arising from numerous origins (see Section BIII–2.6) and include:

— How well is the parameter specified, and are there interactions with other parameters?
— What are the uncertainties in the source data (analytical techniques and associated errors, experimental design, rules for data derivations etc.)?
— Is there a basis for applying the derived parameter value to conditions other than those for which the original source data applied?
— Are values based on a single observation, or a series of observations (in space/time)?
— Does one find similar values for studies performed under almost identical conditions?
— Can the distributions and ranges of parameter values be defined?

Emphasis is put on the need to define as precisely as possible the parameters of concern before attributing values to them. Known interactions with other parameters and factors should not be forgotten. Particular attention should also be given to the source of data from which the parameter values have been derived, in terms of the nature (generic/experimental/from the field), experimental conditions, statistical treatment etc. Even for some well-known parameters (e.g. soil to plant transfer factors), the basic source data can be heterogeneous: for instance, the transfer factors for some elements (e.g. silicon) have been derived from stable element data rather than from tracer experiments used for many of the others.

Besides reliability, another major feature relevant to data use is applicability: the target is to ensure suitability of the data for the purpose envisaged. As noted previously, concerns stem from the fact that performance assessment models are a simplification of a complex reality, they are used for calculations applied to very long time periods, and they are expected to apply to a series of various climate conditions. A major issue is therefore to determine suitable methods by which parameter values can be extrapolated from data sources and this requires an understanding of any likely application of the data.

Finally, the importance of traceability is also underscored in reference (Coughtrey, 1992), this requires the development of a properly documented record of data sources and justification of the assumptions made.

## BIII–2.4. SUITABILITY OF DATA FOR A GIVEN ASSESSMENT CONTEXT

At first glance, suitability seems merely to be the examination of the data accuracy with a genuine understanding of the measurement/derivation techniques, in order to deduce the model accuracy limits (Brown and Kulasiri, 1996). Numerous factors affect measured or derived parameter values (e.g. analytical errors, use of values obtained from the literature instead of actual values, non steady-state conditions ensured etc.) (Coughtrey and Thorne, 1983).

But data suitability is more than this, for several reasons (Rykiel, 1996):

- data are not infallible standards;
- data and models are two moving targets that are intimately linked;
- the validation of data is not absolute, it means only that data have met a specified standard;
- the validation of data is really more akin to the validity of their interpretation;
- it is not possible to assume that any data accurately represent the real system;
- any measurement/derivation is biased by our perception of the system.

In practice, the way by which the suitability of data is decided starts with an account or report from an existing background, then the parameter for which data are sought is assessed in order to decide if it is a key component of the assessment or not. Eventually, the ultimate decision, concerning the data determination for such a parameter, is based upon the comparison of the existing background with regard to the assessment context. This means that it is possible and valid to build so-called “initial” databases for performance assessment models (a better term than “default”), and also that a structured procedure should contain a first part that deals with the initial database construction, and a second part for managing the choice or changes to the initial values before their use.

## BIII–2.5. SELECTION AND REPRESENTATION OF DATA

In practice, biosphere models can usually be classified in one of two families, namely the simple equilibrium models relying mainly upon transfer/concentration factors, and the dynamic models relying on transfer rates (ICRP, 1979). The border between the two is not sharp since the so-called equilibrium models usually contain a small dynamic part restricted to short-term processes such as those describing migration in soil. In any case, the model structure is strongly influenced by the level of description desired and by the availability of data. Indeed, it is recognised that, since data are scarce in number and are subject to large uncertainties over both space and time, the systems modelled, the mathematical nature of system equations and the potential sources of data should all be considered in order to optimise the ‘purpose + model(s) + data’ set (IAEA, 1989; ICRP, 1979). A compromise must be reached in the end before model application, since for instance:

— mechanistic modelling for assessment purposes is usually considered to be more preferable than mere fitting, because the performance of safety studies on the basis of mechanistic models helps focus on the main compartments and looks more accurately at the most critical compartments (ICRP, 1979); moreover, mechanistic models can also be constructed part by part, to help model radionuclide transfers under conditions for which there is no analogue at the present time;
— initial (better than default) values are the most easy to obtain but they can lead to overly conservative results difficult to defend because they are rather theoretical (IAEA, 1982);
— more than one set of data can describe equally well the behaviour of the final output of a system (ICRP, 1979; BIOMOVS II, 1996).

An important issue is the use of “high-level” aggregated parameters representing ecological systems (e.g. ratio between ground deposition and radioactive level in animal meat), versus the use of simple transfer parameters between elementary compartments (e.g. soil to plant). In fact, it appears that the former present some advantages when dealing with well defined natural systems, whereas parameters at “lower levels” are difficult to assess. Conversely, simple compartment-to-compartment transfer parameters are usually required for describing agricultural systems, the diversity of which, in terms of agricultural routes, farm products, consumption patterns etc. leads to separate assessments of each pathway (IAEA, 1994) and makes it difficult to propose relevant aggregated values, even if they are found to be more robust than their components in some specific studies (SSI, 1996).

Sometimes, aggregation is definitely not a matter of choice, but arises as a necessity for various reasons. For example, the use of the Kd parameter is due to constraints linked to weakness in physical, chemical (De Marsily, 1986), and biological understanding of some of the processes involved in the underlying components. At another scale, it is very difficult to obtain actual data concerning the structure of agricultural systems, because agricultural statistics are usually collected by region, making it impossible to extract information for single farm structures (Grigg, 1992). Such difficulties increase when there is an attempt to collect historical data, for instance, if some agricultural structures of the late 19$^{th}$ or early 20$^{th}$ centuries were considered to be relevant examples of reference biospheres because they are the last examples of genuine self-sustained systems in the Occident.

The study of soil to plant transfer factors has resulted in extensive discussions about the issue of data definition. The IUR report (IUR, 1984) is an excellent example of what can be documented in the collation of data derived from a wider database. In this document, one reads that for a given transfer factor $TF_{actual}$ from soil to plant, the experts have gone beyond the display of a single figure and have preferred to express the data value as:

$$\ln TF_{\mathrm{actual}} = \left(\ln TF_{\mathrm{standard}}\right)_{soil,\,plant} + \alpha \mathrm{pH} + \beta \mathrm{OM} + \delta$$

where:

soil and plant are qualitative factors (sand, loam, clay, ... , cereal, fodder, roots, ...);
pH and OM (organic matter) are covariates; and
α, β, δ are numerical coefficients which are obtained through the performance of linear regressions on the initial database collected by IUR, which contains results of individual well-controlled experiments.

The expression was extended a few years later (IUR, 1987), in order to take into account more covariates like the upper soil layer depth or the irrigation rate.

Such a way of dealing with transfer factors has been generalised for the main biosphere parameters, at least by extensively using categorisation with respect to soil (Kd), types of plant and animal, but also covariates, in expressions such as:

$$\ln TF_{fish,Sr} = \alpha - \beta \ln[Ca]_{water} \quad \text{(Coughtrey and Thorne, 1983)}$$

Sometimes, potentially important factors are only mentioned as marginal information (e.g. for crops: method of management, climate, chemical form of radionuclides etc.), but if they are not formally controlled, they contribute to the overall random variability of data (IUR, 1987), which may be unacceptable in terms of range, whereas proper statistical management could reduce the effect of significant controlled factors. Therefore, such methods are sometimes an interesting means for limiting the residual uncertainty that each datum carries. They also permit an effective use of sparse data and enhance the representativity of the transfer factor as an over-simplified model, in the same way mitigating the consequences of extrapolations. However, one should also be aware of the difficulty of applicability when there is a lack of data (e.g. very few or no data at all for some radionuclides), or when the covariate behaviour is uncertain.

Whatever the level of accuracy concerning the management of controlled factors and covariates, it remains a fact that spatial and temporal variabilities of parameters often are physically significant, even when conditions are considered homogeneous. It has been shown (Bachhuber et al., 1985) that measurements of soil Kd on a single $100 \times 150\ m^2$ field plot produced values ranging up to one order of magnitude for some radionuclides such as zinc, cobalt, cadmium, cerium and ruthenium, and a factor of 3 for critical ones such as caesium and iodine (Figure BIII–2).

In addition, the records of meteorological statistics often underline the spatial variability of important parameters (e.g. precipitation and evapo-transpiration) over the same regional unit (easily a factor 3 in France), and also the temporal variability (during the last century in Paris, $P_{min} = 270$ mm and $P_{max} = 880$ mm, $\mu = 628$ mm, $\sigma = 88$ mm) (INRA/SCEES, 1989) which raises the issue of how to deal with temporal variability.

All these aspects shed light on the limitations of the notion of site specificity: spatial and temporal variabilities occur at all scales, leading to the conclusion that there is no natural scale of measurement. Such a consideration makes it understandable why, when there is a lack of information at a particular scale of modelling, it is not unreasonable to take advantage of data obtained at another scale.

For instance, results from large scale modelling, (e.g. in relation to future climatic conditions) may have to be downscaled for application to a specific site. Indeed, one question is to know whether site specificity is necessary or only valuable (or not interesting at all), and especially what are the arguments against generic studies (knowing that each generic study has features that link the study to the system under assessment: e.g. broad basic assumptions such as cold/temperate climate, coastal/continental location etc.).

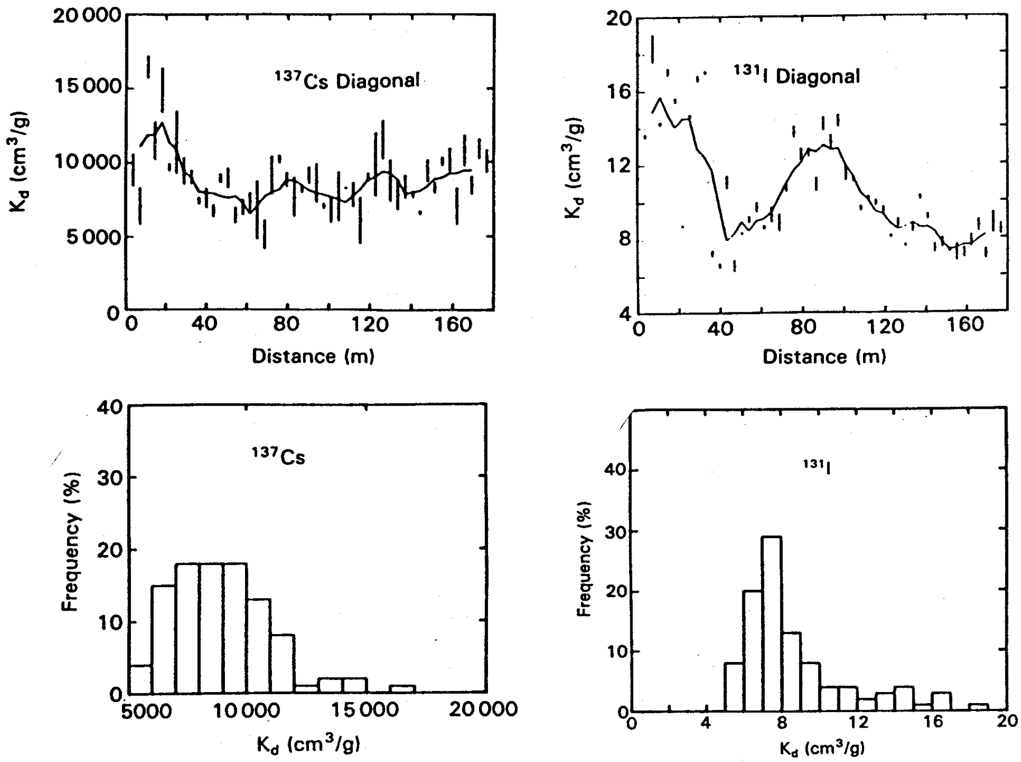



*FIG. BIII–2. Example of spatial variability at field scale.*

In order to assess the answers, it could be useful to explore the following secondary questions:

— what are the individual features of a particular site: what is unique about the site compared with another site located in another valley, region, country etc;

— what is linked to some specific but not local features: what data could be obtained from different locations where similar conditions exist;

— what could be totally generic: what are the data that could be extracted from an international database without too many questions about the applicability of their use?

Another question to ask is whether the assessment context should/could define rules for deciding if there are requirements concerning site specificity or the use of generic data. Perhaps, it is possible to envisage fixing such rules from the start, with allowance for some level of flexibility.

## BIII–2.6. MAJOR SOURCES OF UNCERTAINTY

The first Technical Report issued by BIOMOVS II (SSI, 1993) provides an overview of the main sources of uncertainty affecting the reliability of results from environmental transfer models. The following are relevant to the present topic:

At the start, the specification of the problem sets out the criteria against which all assumptions and subsequent choices will be checked. It covers:

- The intended use of the results: site selection, licensing, illustration etc.
- The temporal resolution adopted: this guides the choice of what data will need to be treated as time-dependent, e.g. subject to seasonality, or integrated over certain time periods (the notion of seasonality is not important for dose seasonality, since doses are annual, but it is important for the proper determination of key data, such as the water budget for instance).
- The spatial context: this could lead to the choice of local data rather than global data; it may be determined by the assessment context.
- The source term: this contributes to the database selection, or in the setting of checks on extrapolations of parameter values from existing databases. It is determined by the assessment context.

Then, for a given assessment context and model(s), the estimation of parameter values, even if directly obtained from experiments, is tainted with uncertainty because of:

- the measurement errors associated with any observation;
- the genuine stochastic nature of some parameters (if ever);
- the differences sometimes observed between field data and data obtained from laboratory experiments;
- the dependence of some parameters on factors that were not controlled during measurements/estimations;
- large variations of parameter values through space and time;
- the lack of observational data on which to base parameter values;
- the failure to take account properly of actual correlations between certain parameters (e.g. the link between $Kd_{soil}$ and the transfer factor soil→plant);
- the use of values obtained under conditions quite different from those currently set by the assessment context, the use of parameters outside their range of applicability, the inappropriate use of generic values, even if such uses are sometimes unavoidable;
- the aggregation of short-term processes in one single parameter in models;
- the performance of calculations over a very long time scale, along with uncertainties about the environmental/human conditions that increase dramatically with time;
- the errors made by the modeller, who may not be familiar with the determination of parameter values.

## BIII–2.7. SENSITIVITY AND UNCERTAINTY ANALYSES

Since data are uncertain for various, known or unknown, controlled or uncontrolled reasons, it is sensible to complete any expression of an expected parameter value by providing an indication of the extent of uncertainty. The first term could be qualified as “typical, most likely to occur”, whilst the second could be represented as, say, a 95% confidence interval or a range of values quoted in literature etc. (IAEA, 1994; IUR, 1987). The aim would not be to consider only the nature and the value of the uncertainty of the data, but also to consider the final uncertainty that would be attached to the results of calculations, since the reliability of model predictions is affected by the estimation of the parameter values (IAEA, 1989).

Concerning the single estimate of a variable, it could appear trivial to consider as a first step that the so-called expected value of a parameter could be calculated on the basis of the computation of an arithmetic mean. However, such an approach is valid only when data initially come from consistent sets of observations; otherwise, the use of the geometric mean is recommended in the literature as a way to properly average data over space and time (IAEA, 1994). Of course, the sources of data should be qualitatively similar (e.g. a compilation of experimental data), otherwise the averaging would be difficult to control and justify (e.g. mixing of data that have been averaged already with experimental data).

Without going too deeply into the technical details, any discussion related to the type of averaging and the choice of distribution functions raises particular issues. For instance, it is well known that given $y_1$, $y_2$, ..., $y_i$, ... as independent stochastic variables of any probability distribution function (pdf), but for which it is possible to calculate their means $\mu_i$ and variances $\sigma_i^2$, then the distribution of the sum of these n independent random variables tends to the normal distribution when $n \rightarrow +\infty$, and this under fairly general conditions (Central Limit Theorem) (Hald, 1952). Unfortunately, whatever the type of development of this theorem (Laplace-Liapunoff (CEA, 1978), Lindberg (Saporta, 1990)), one faces difficulties in practice, which are first the rather small value of n, and second the fact that some $\sigma_i^2$ could be non negligible with respect to $\Sigma_i\sigma_i^2$, contrary to what is expected in theory.

A third difficulty often encountered lies in the fact that the standard deviation of populations tends to increase steadily with their size: i.e. for a random variable Y, $\sigma_Y \propto n$. The remedy usually used in such cases is a "stabilisation of variance" technique by recourse to the logarithmic transformation ($Y \rightarrow \ln(Y)$) (Draper and Smith, 1981).

All these statements justify the frequent use in the literature of the normal and lognormal functions. Nevertheless, it is sometimes difficult to ensure that a parameter pdf, even for concentration/transfer factors, will fall in one or the other possibility (MacGee et al., 1995). Therefore, it could be more useful simply to use distributions, such as uniform and log-uniform, that have the advantages of being easily constructed and bounded, in order to focus on the distribution tails, which are of interest in safety assessments. Such distributions are all the more justified when there is an obvious lack of knowledge which prevent use of objective probabilities (frequentist point of view), thus allowing only the test of assumptions based on subjective considerations. Indeed, experience shows that subjective pdfs are used very often, not only because of the previously mentioned lack of actual statistical data, but also because they can simplify some procedures (less effort to develop), provided that the subjective pdfs are more cautious than the expected "natural" variability/uncertainty.

Hence, when statistical analyses do not provide relevant frequential information, when the data are too scarce, or when they do not even exist (extrapolation), then past studies have demonstrated that a practical solution is recourse to subjective decisions (IAEA, 1994) as a fundamental part of the assessment. The Dry Run 3 exercise provided the opportunity of developing a particular approach for the elicitation and aggregation of data (Sumerling, 1992), where most pdfs were derived by expert judgement. The interest and applicability of the discussion is certainly worth extending to our subject-matter and is a main topic of Section BIII–2.

In summary, the methodology developed in the Dry Run 3 exercise consisted of grouping experts with experience in modelling, theoretical applications, and field and laboratory measurements, in order to reach some form of consensus on pdfs. However, the rationale behind the decisions, and the proper documentation of the disagreement, are certainly more important than the consensus itself. The implemented main stages of the approach, which are not unique for such a purpose, were:

- an introduction: objective of the meeting;
- an investigation of the potential motivational biases of participants;
- the definition of the parameters of concern, and of the aggregations envisaged;
- an assessment of the existing methods for measuring or estimating parameter values and uncertainties;
- the search for factors affecting the parameter variability and for the initial assumptions driving the estimation conditions;
- the identification of the main sources of uncertainty;
- the sharing of participant's knowledge;
- the encoding, i.e. the derivation of the pdfs with their levels of confidence;
- the final verifications.

BIOMOVS II also issued some guidance for the definition of pdfs (SSI, 1993).

Besides the determination of the data estimates and pdfs, discussions should also deal with the analysis and determination of parameter values for the correlations that are likely to exist among the variables under examination (outside those induced by the model structure) (Jorgensen, 1994; Coughtrey, 1992).

Finally, experience has shown that the amount of effort required to determine all the parameter values used in a model, and the level of confidence associated with them, may not be as large as it seems, since their influence on the model output (calculation endpoints) is usually not at the same level, it will depend first on the model structure, and second on the input uncertainty (SSI, 1996). As a consequence, it is recommended that a sensitivity analysis (SA) should be performed on the models, in order to obtain evidence about the set of main parameters, the variability of which best explains the output variability. Although there is an extensive literature (SSI, 1993; IAEA, 1989), experience has highlighted the weakness of modellers when conducting SA and using statistical techniques attached to SA (SSI, 1996). Although more practical experience is certainly required in that domain, according to past studies (e.g. programmes like BIOMOVS II and EVEREST) it is nonetheless possible to try to establish lists of important biosphere parameters, even if such lists are provisional and dependent upon particular assessment contexts and endpoints. Such lists would be of interest when developing Example Reference Biospheres, in order to focus attention, given time constraints, on the most important parameters that require the application of a protocol for data selection. It should be remembered, however, that the results of sensitivity analyses depend on the scenario specifications and the radionuclide type.

These considerations do not refer to the appraisal of the qualitative uncertainties, which are expected to be addressed either by the assessment context or during conceptual model development.

### BIII–2.8. CONCLUSIONS

It is apparent that guidance for the application of data to assessment models cannot be restricted to a mere indication of the best data references found in literature. Rather, it has been previously demonstrated that data gathering and use are located at the cross-roads of several overlapping fields.

Although a lot of questions have been raised, they should not prevent people from performing their analyses; neither do they put at stake what was done in previous biosphere assessments, provided that the rationale behind decisions was clearly stated. Indeed, these issues are to be considered more as safeguards against overconfidence when managing data. In particular, it seems important for each study to build a consistent framework in order to isolate clearly and logically the main topics to be addressed, and to structure the large amount of information currently available in them. Practically, a protocol for the derivation of data, as outlined in Section BIII–2 certainly will constructively assist the management and documentation of data selection.

## BIII–3. DEVELOPMENT OF A PROTOCOL FOR THE DERIVATION OF DATA

### BIII–3.1. ELICITATION AND USE OF EXPERT JUDGEMENT

#### BIII–3.1.1. Rationale

At the present time, there is an extensive literature dealing with the management of expert judgement and the development of elicitation methods (see (Bonano et al., 1990; Woo, 1992; Watson, 1992; Thorne and Williams, 1992)). This literature, however, is mainly oriented towards the determination of pdfs by groups of experts, which means that it will be necessary to check carefully the approaches used if they are to be adapted for building a generic protocol for the derivation of data. For example, pdfs are not always sought by the assessor, who might be satisfied with single values only; in such a case, one could ask whether a data protocol should be adapted to such a demand or whether it is better to elicit pdfs and deduce any quantile from them. Another example is the case when a small assessment team elicit data from various references; this case is common and rather different from recourse to the use of a panel of experts.

The main requirements for the development of a data protocol are thus manifold. First, the overall objective is the determination of relevant data values for performing calculations, and the reduction, or at least control, of the associated uncertainties. In particular there is a need for data, whatever their actual availability, in order to justify acceptable decisions, which is a different target from the phenomenological modelling of nature. Consequently, and second, such a protocol should be a step-by-step approach, enabling traceability, iterations and feed-backs. It should then enable (and enhance) the management of heterogeneity in information (qualitative/quantitative/discrepancies in availability), the explicitness of rationales behind decisions, and more generally the management of expert judgement, which is fundamental in the safety assessment realm.

Even if applicable to other purposes, the data protocol is intended to focus on biosphere modelling issues, to ensure consistency with regard to other components of the integrated safety assessment, especially with the biosphere interface(s). This structured procedure should document any peculiarities with respect to the main data types, in terms of availability and homogeneity, and state the main types of existing databases (internationally accepted, site-derived etc.). It is also intended to be a reminder that the derivation of data is just one piece of the overall BIOMASS Methodology, by recalling the necessary links with the other components (see also Section BIII–4), particularly the assessment context. Last, the protocol should help with deciding if data are then suitable/applicable for a particular purpose.

### BIII–3.1.2. Data management structure in the overall biosphere assessment

Figure BIII–3 illustrates the relationships between data types, data availability and data requirements in a structured approach to data management. The top part of Figure BIII–3 shows that data management begins after the development of the other BIOMASS Methodology components (i.e. data requirements become apparent from the assessment context, the description of the biosphere system with its critical, or other potential exposure group(s), and information on the models to be used). Some of these activities may occur in parallel (e.g. database/mathematical models). The bottom part of Figure BIII–3 shows that one seldom starts from scratch, and that there is a need to manage various types of data, from prescribed databases to special data interpreted from experiments, through to other types of existing data that are more or less well-accepted.

Various comments on Figure BIII–3 can be put forward. The first part of this figure defines the data requirements with an emphasis on some mutual iterations with the main components of the BIOMASS Methodology: as discussed in Section BIII–2, sometimes mathematical models drive the data requirements, sometimes mathematical models are driven by the data availability.

The data protocol (developed in Section BIII–3.2) focuses on the four branches (I to IV) between “evaluation of available information” and “performance of assessment”, even though Figure BIII–3 addresses the overall structure of data management in the biosphere assessment. Thus, Figure BIII–3 demonstrates that the most difficult part of data management is branch (IV) (i.e. where there are few or poorly characterised or no data), and this justifies the implementation of a formal elicitation procedure (*cf.* Table BIII–1 in Section BIII–3.1.3).

It is taken for granted that data are key for the assessment. In this protocol, the rationale for the data classification method is availability and homogeneity in terms of sources (or references). The data protocol applied to branch (I), i.e. for prescribed data found in international databases, will certainly be extremely simplified (identification of data required and mere extraction of the most relevant values). For proper documentation (traceability), the protocol is nonetheless of interest for branch (I). Hence, even if prescribed data are considered, a data protocol aims at demonstrating that selection of data is made in an explicit way. This is also the case for branch (II) for which data come from widely accepted databases or other kinds of well characterised data. Branch (II) data also show a good fit between the assessment context and the available well characterised data; the loop after “update of methodology” can help with enhancing such databases.

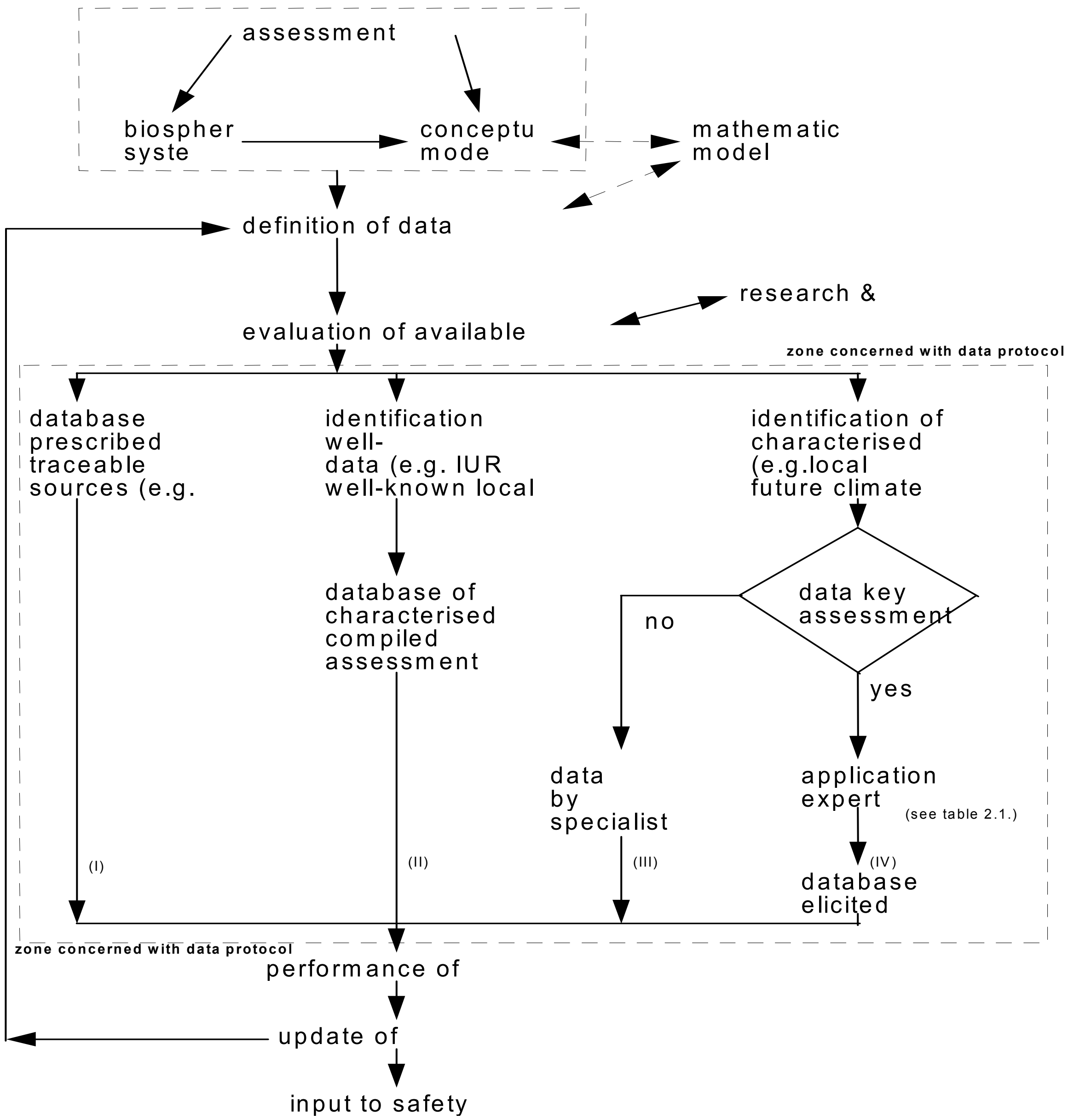



*FIG. BIII–3. Relationships between data types, data availability and data requirements for structured data management.*

Branch (III) data could be compiled by the implementation of the data protocol by one person from the assessment team specialist since the data are not considered to be key for the assessment. The database created through branch (III) should be considered at a lower level than I and II (because it is assessment specific). The treatment of branch (IV) data is more dependent on basic scientific literature concerning experiments and, because the data are key for the assessment, it is recommended that selection should be accomplished through expert elicitation and implementation of the full data protocol.

The test for the branching of (III)/(IV) carries an implicit link with the modelling (through sensitivity analyses).

### BIII–3.1.3. Major steps in a formal data elicitation

There are instances (Section BIII–2.7.) for which it is deemed useful to have recourse to a formal data elicitation procedure, where a group of experts is involved for performing the task. According to Figure BIII–3, such an approach is especially relevant for branch (IV), related to poorly characterised data that are key for the biosphere assessment. The main steps of a data elicitation procedure are indicated in Table BIII–1. It is recognised that the protocol for the derivation of data (Section BIII–3.2) could be used in order to structure the discussions and the documentation of them, and to help keep consistency with the overall data management.

TABLE BIII–1. MAIN STEPS FOR THE FORMAL ELICITATION OF DATA BY A GROUP OF EXPERTS

| | | |
|---|---|---|
| **(a)** | **Assessment specialists define parameters for which elicitation is required** | |
| (b) | Assessment specialists define range of expertise required | |
| (c) | Select experts, typically using a skills matrix and taking account of availability | |
| (d) | Establish expert group | |
| (e) | Elicit data | |
| | (i) | Educate experts on project, data requirements, making probabilistic judgements and avoiding biases. Undertake preliminary elicitation exercises |
| | **(ii)** | **Explore expertise and potential motivational biases of expert group members** |
| | **(iii)** | **Review and agree definitions of quantities to be elicited** |
| | **(iv)** | **Explore variability of quantities to be elicited and factors affecting those quantities** |
| | **(v)** | **encode pdfs of elicited quantities (including uncertainty/variability)** |
| (f) | Document elicitation | |

Where elicitation is by assessment specialists, only the following steps (shown in bold above) are applicable: a, e/ii, e/iii, e/iv, e/v and f. The data protocol can be used to help structure steps e/iv, and e/v.

## BIII–3.2. FORMALISATION OF A DATA PROTOCOL

Practical approaches have been described previously (Nirex, 1994; Cojazzi et al., 1997; Sumerling, 1992), the first of these being particularly valuable for helping to structure the protocol. Figure BIII–4 summarises the steps of a protocol for the derivation of data that is described in more detail in the following text.

### BIII–3.2.1. Step (1): Introduction to the protocol

— **Establish the assessment context** (iteration with the BIOMASS Methodology component "assessment context"). The assessment context should contain information related to:

- the purpose of the assessment, driving the required level of detail, and the level of rigour because the biosphere is a measuring instrument;
- the end-points of the assessment (to be checked with mathematical models), the type of calculations (from simple deterministic to fully stochastic);
- the assessment philosophy (from reasonable to cautious) *(cf. the "Critical and other potential exposure group" component)* that has an influence on the level of confidence required (safety factors, constants/confidence intervals, link between endpoints and constraints for accepting/rejecting an assessment);

- the main features of the repository system and the site context;
- the source-term (radionuclide spectrum) and the interface biosphere/other compartments (models used);
- the time frame, time dependencies (what parameters should depend on time and how, evolution through time, particular time steps, etc.)
- the societal assumptions (list of parameters defining a society).

— **Examine the data requirements** resulting from the biosphere system justification and biosphere system description components, the critical group and other potential exposure group considerations, and the mathematical model(s).

— **Establish the list of parameters** for which data are required by the assessment model(s) to be used: the list constitutes the initial set of required quantities (see the 2$^{nd}$ point under "Structuring" for adding "hidden" parameters) *(cf. "Biosphere description" "Critical Group" and "Modelling" components).*

The link with models should be considered as a whole (Figure BIII–3, upper part); in particular, assessment models should provide quantitative and qualitative information, and they should not contain variables for which there are no data at all (modelling issue).

— **Compile the available information**: existing databases (either prescribed, generally accepted, personal work); all the databases should contain any caveats and limitations concerning their uses.

**BIII–3.2.2. Step (2): Structuring**
(i.e. overall review)

— **Take the initial set of required quantities**; establish the associated data pattern (way to optimise the data acquisition according to the main data types, based on data availability and homogeneity: see branches I to IV in FigureB III–3).

— **Go through the list and explore the potential direct relationships between parameters**: note relationships and reduce the initial list accordingly in order to create a second list of required quantities; use the existing information (see top of Figure BIII-3) and refine what is necessary by implementing structured procedures (e.g. an interaction matrix)

— **For each required quantity** (i.e. associated to a parameter)

**(a)** **Define the quantity:** nature (i.e. verbally), dimensions, equation and units of the parameter:

- If the model is already known, use the same format for consistency.
- Indicate briefly the method for assessing (from the literature) or measuring (from experiments) the parameter. If possible, include references to existing databases:
  - if it is straightforward (numbers directly applicable), report it;
  - if not, highlight the underlying parameters, extend the second set of required quantities and return to step(2a).

(b) **List the relevant factors and related information that have an influence** on the value of the parameter, independently from the specific study:

- information usually required for a relevant assessment of the quantity;
- usual sources of uncertainty/variability, including the lack of data;
- identification of the existence of potential correlations between elicited data (for comprehensiveness, use a structured approach like interaction matrices).

(c) **List the relevant assumptions driving the actual data determination**

Cross-check with the specific study according to its assessment context, the assessment model structure, the iterations from the "Critical group" and "Biosphere description" components, and the previous factors and related information. In particular, clearly identify the sources contributing most to uncertainty.

— **go to the next required quantity**

**BIII–3.2.3. Step (3): Conditioning**
(i.e. qualitative decisions for a specific study)

**For each required quantity:**

— **Define the nature of the estimates required** according to the assessment context components (pdf, upper limit/lower limit /average, or even intuitive values) and report the current sources of information that will be chosen and their credibility; cross-check the sources for their relevance against (2b). Indicate the derivation procedures from existing data; test also the extrapolation methods if necessary.

— **If the data are not available, report the derivation procedures** (e.g. chemical analogy) if they exist.

— **Identify potential bias.**

— **Specify strength of correlations among data.** Discuss implications for data selection.

— **Identify what implications are potentially attached to parameter value extremes**. Analyse qualitatively the consequence of low or high data values on the endpoint evolution. Test with(2c). Iterate with the modelling.

**BIII–3.2.4. Step (4): Encoding**
(i.e. quantitative decisions = data determination)

**For each required quantity:**

— Assess and report the quantity of interest.

— If required, ensure consistency with existing correlations; make explicit caveats concerning the associated modelling issues (e.g. $Kd_{soil}$ and $TF_{soil\rightarrow plant}$), in particular, make sure that various experts can interact.

— **Transform values in the case of mathematical relationships** between parameters, in order to complete the initial set of required quantities.

— **Document the quantities**: see the following output format.

**BIII–3.2.5. Step (5): Formal output format**
(i.e. Traceability and Communication)

Aside from documentation of the data, this part should contain the information to enable the performance of the protocol again, for instance in order to up-date a parameter value without requiring the performance of the initial exercise from scratch.

**For each required quantity document:**

— Definition of the parameter to be qualified.

— Major factors that have an influence on its value, major sources of uncertainty and variability.

— Existing correlations with other parameters.

— Major assumptions attached to the actual data determination.

— Numerical estimate(s).

— Sources of information (literature, expertise, experiments, reviews etc.).

Part or all of this information could also be used for the construction of databases, bearing in mind that one important field could be an indicator that the data protocol had been performed for selecting parameter values.

BIII–3.3. EXAMPLES OF APPLICATION

The following examples are intended as mere illustrations of the applicability of the data protocol. They are based on the readily available literature which is directly interpreted for this purpose only. These examples should not be considered at the same level as the Example Reference Biospheres (Part B) since these were carried out in a different context, i.e. for another purpose.

**BIII–3.3.1. Determination of an ingestion dose factor from a prescribed source**

(1) *Introduction*

— Assessment context: it is assumed that one performs a radiological impact assessment with the help of a given "normal evolution" scenario for which the internal exposure by ingestion is to be evaluated. It is assumed that the dose should be an average annual individual dose for an adult (link with the "Critical group" component) incurring a chronic exposure through his adult life.

— Data requirement: it is assumed that the required quantity to be assessed is the ingestion dose factor for $^{129}I$.

— List of parameters: it is restricted to the parameter designated as $DF_{ing,I129}$, expressed in Sv $Bq^{-1}$ (link with the "Modelling" component).

— Available information: the assessors have usually at hand documents such as the ICRP reports (ICRP, 1995), the IAEA/Basic Safety Standards (IAEA, 1996) and internal compilations of data.

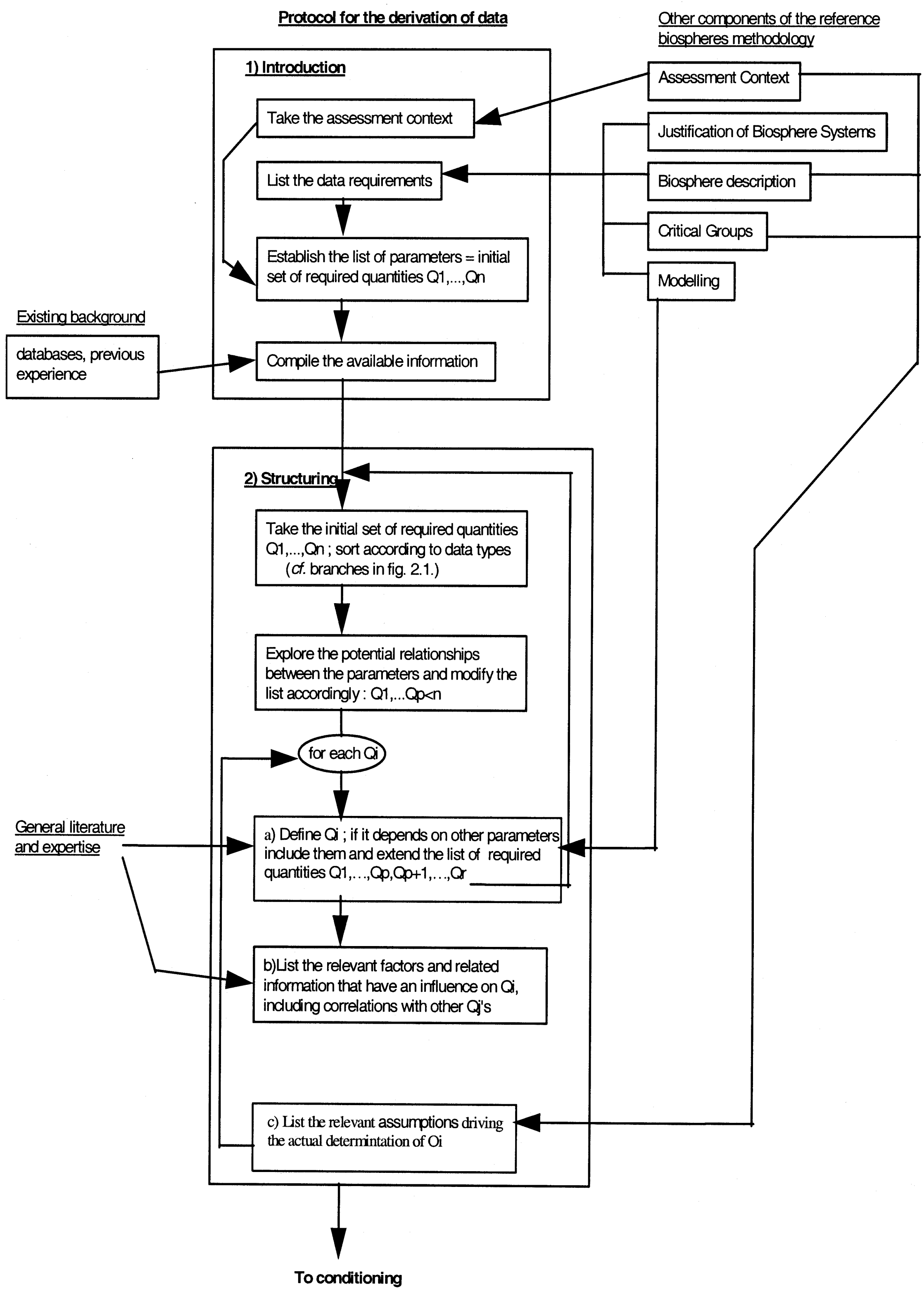



*FIG. BIII–4. Summary of the protocol for the derivation of data.*

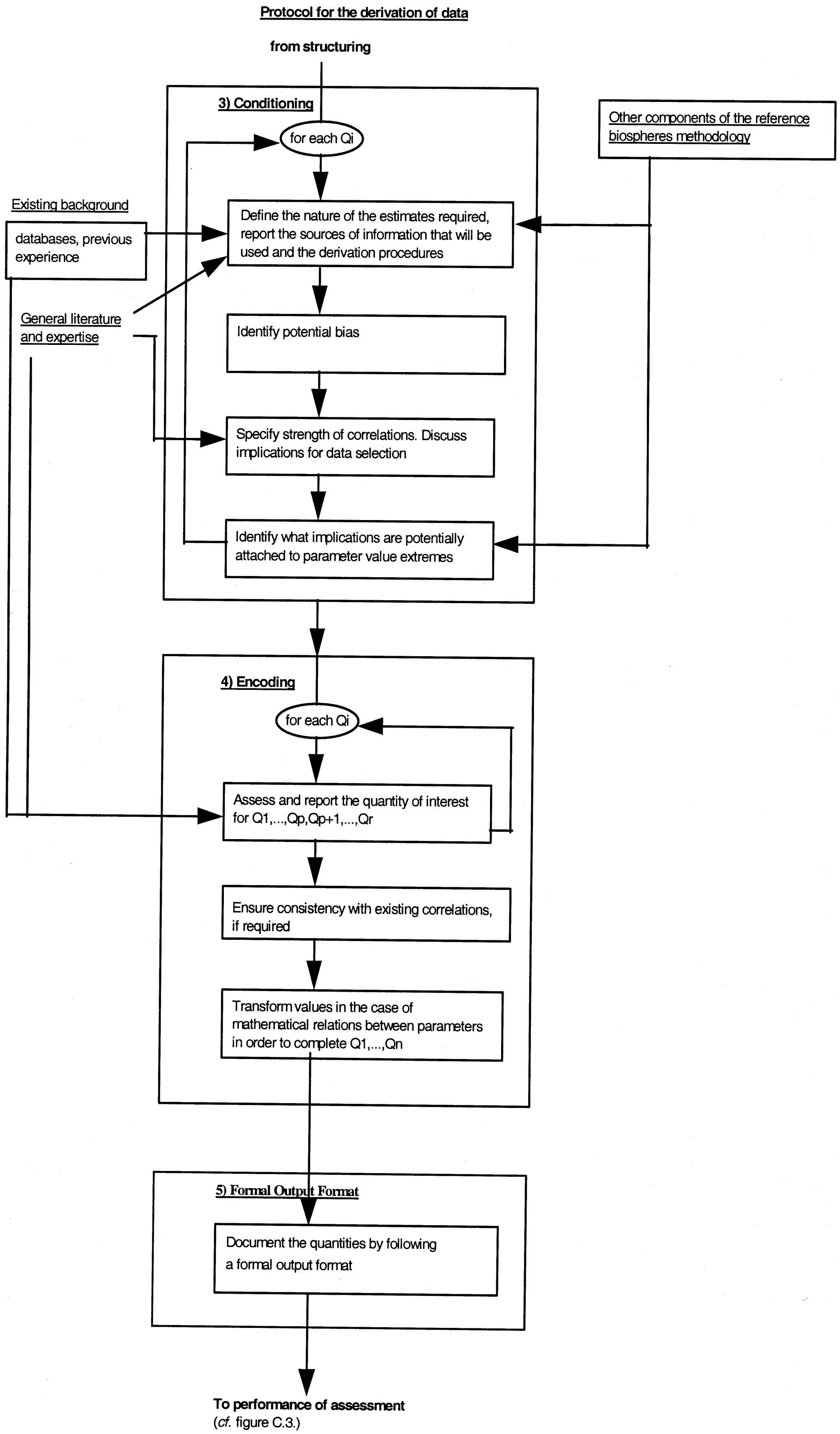



*FIG. BIII–4. Summary of the protocol for the derivation of data (continued).*

(2) Structuring

— Data pattern: the ingestion dose factor belongs to the category of data which are usually prescribed by widely recognised sources. Here, it is assumed that the IAEA/Basic Safety Standards (IAEA, 1996) (BSS) is a relevant reference for the purpose of this example, because it is the result of an international agreement, and integrates information from the ICRP.

— Definition: the ingestion dose factor, expressed in Sv $Bq^{-1}$, is the measure of the radiological impact associated with the ingestion of a given radionuclide. In the safety assessment of radioactive waste disposal, it is a parameter usually assumed as a constant to be extracted from relevant international databases like the BSS.

— Relevant factors: the BSS address the assessment of individual doses, the consequences of which are not deterministic. They show a variability of the ingestion dose factor with respect to the age of the individual, with $DF_{ing,I129}$ ranging from 1.1 $10^{-7}$ Sv $Bq^{-1}$ at 17 y to 2.2 $10^{-7}$ Sv $Bq^{-1}$ at an age between 1 and 2 y. The ingestion dose factor for an adult member of the public appears the same as that for a worker. There are no other sources of uncertainty/variability mentioned, but one should be aware that the ingestion dose factor depends on the radioisotope. It should also be mentioned that the retention of radioactive iodine is influenced by the amount of stable iodine in the diet, and that the total intake of iodine is determined by physiological constraints, leading to a limit on the maximum radiological impact due to $^{129}I$ to a few tens of mSv per year.

— Relevant assumptions: for the actual data determination, $DF_{ing,I129}$ will be characterised for an adult, hence without any uncertainty, because of the context previously set.

(3) *Conditioning*

— Nature of the estimate: single value given by the literature (here, the BSS).

(4) *Encoding*

— $DF_{ing,I129}$ = 1.1 $10^{-7}$ Sv $Bq^{-1}$, according to the BSS.

(5) *Formal output format*

— Determination of the ingestion dose factor for $^{129}I$, $DF_{ing,I129}$, expressed in Sv $Bq^{-1}$.

— The exposed individuals should be adults more than 17 y old, and should not incur deterministic effects from their exposure, which is impossible with $^{129}I$.

— $DF_{ing,I129}$ = 1.1 $10^{-7}$ Sv $Bq^{-1}$, according to the IAEA/Basic Safety Standards (IAEA, 1996).

#### BIII–3.3.2. Determination of a soil Kd and a soil-to-plant transfer factor from scientific literature and/or expertise

The major source of information for this Section is Dalrymple and Willows (1992), together with Dalrymple (1987), Watkins et al., (1997), and IUR (1992). Relevant information on other quantities and past exercises is also found in Brown et al., (1997) and IUR (1987).

The intent of this Section is not to give all the details that should be written at each protocol step; rather, its purpose is to illustrate where each piece of information should be located.

(1) *Introduction*

— Assessment context: for the performance of a generic exercise, the transfers of radionuclides through a small-farm system under temperate conditions are evaluated. In particular, for iodine entering the system by irrigation, it is necessary to determine its accumulation in soil and transfer from soil to plant. The final end-point is assumed to be a deterministic annual effective dose (then the evaluated quantities will be either directly obtained single values or a relevant quantile extracted from a pdf); the assessment philosophy is taken as realistic, i.e. based on the selection of best estimates; the repository contains iodine 129; and the cultivated soils are sandy and carry various types of plants which are supposed here to behave as pasture does.

— Data requirements: it is assumed that the required quantities to be assessed are the sorption coefficient in soil for iodine, $Kd_I$, and the soil-to-plant transfer factor for iodine, $TF_{soil,I}$.

— List of parameters: $Kd_I$, expressed in $m^3\ kg^{-1}$, and $TF_{soil/plant,I}$, dimensionless (link with the "Modelling" component).

— Available information: the assessors usually have access to overall compilations such as IAEA/IUR Technical Reports Series No. 364 (IAEA, 1994), databases from the International Union of Radioecologists, and various publications dealing with particular experiments and specific assessment models.

(2) *Structuring*

— Data pattern: for a generic exercise, $Kd_I$ and $TF_{soil/plant,I}$ can be considered as belonging to well-characterised databases (IUR documents for instances), but it is often necessary to check that their content is in accordance with the future use of the quantities. For the illustration developed in this Section, it is assumed that the existing values just consist of a part of the available information and that they are not defined from the beginning.

— Potential direct relationships: no formal relationship (i.e. mathematical).

**Kd**

— Definition: the sorption coefficient is the ratio of the activity per unit mass of solid over the activity per unit volume of liquid, expressed in $m^3\ kg^{-1}$. This definition is only valid if sorption is defined as being determined by various reversible, time-independent and concentration-independent processes. If not taken directly from existing databases, Kd can be measured through laboratory and field experiments on stable or radioactive isotopes (no further details given here).

— Relevant factors: according to literature and expertise, one finds pH, Eh, temperature, mineralogy, soil content of organic matter, water composition and flow rate, experimental conditions, time allowed for reaching equilibrium, bacteria. There is little information concerning the behaviour of $^{129}I$ in soil, since the available data are derived from the behaviour of other iodine isotopes. There is certainly a negative correlation between Kd and $TF_{soil/plant}$, because a strong Kd will limit the element mobility and availability for plant uptake.

— Relevant assumptions: at minimum that equilibrium is established, the soil type is set (sandy in the current exercise) and is homogeneous through the root zone, which is the zone concerned in the case of the transfer factor (e.g. 10 cm for a pasture). The organic content of the soil could be a major source of uncertainty.

**$TF_{soil/plant}$**

— Definition: the soil-to-plant transfer factor, or concentration factor, relates the fresh weight activity in edible plants ($Bq.kg^{-1}$ fresh weight) to the activity in soil ($Bq.kg^{-1}$ dry weight to a defined depth), assuming equilibrium between the two compartments. If not taken directly from existing databases, this quantity is normally assessed using an empirical ratio measured through laboratory experiments (plants in pots or lysimeter) or field experiments (no further detail given here). The dimension equation (dry/fresh weight) is source of confusion when exploring databases; conversion factors concerning dry weight content of fresh products are given in reference (IAEA, 1994).

— Relevant factors: according to literature and expertise, one finds the chemical form of the element, the time allowed for ensuring equilibrium, the soil characteristics, the plant species, the water content in plant, the technical route of the agricultural system, for iodine, the stable iodine concentration etc. There is certainly a negative correlation between Kd and $TF_{soil/plant}$, because a high Kd may limit the element mobility and availability for plant uptake. Other processes can be worth considering in specific situations, such as active mechanisms for uptake of elements by some plant species.

— Relevant assumptions: at a minimum that fresh weight in plant is assumed; uniform nuclide distribution through the root zone; the quantity is averaged over one full year including seasonal variations, and averaged over a number of successive years for given climate conditions, which are taken as temperate for the current exercise. Plant type is a major source of variability, but in this exercise, the only type is pasture.

(3) *Conditioning*

**$Kd_I$**

— Nature of the estimate: single value, qualified as best estimate; it is assumed for the illustrative purpose that the IAEA/IUR report (IAEA, 1994) (as an example of an already existing data source) and the results of the elicitation exercise (Sumerling, 1992) (as a way to include the recourse to elicitation procedures) are relevant references. Due to the assessment philosophy, the median of the confidence interval is assumed to be the value of interest when interpreting the elicited confidence intervals of Sumerling (1992). This reference did not consider selection of single values.

— Consequence of correlations: due to the existing correlation between Kd and $TF_{soil/plant}$, it is unlikely that a high Kd would be associated to a high $TF_{soil/plant}$.

— Consequences attached to extreme outcomes: according to the usual modelling (which is subject to variations for some radionuclides), a high Kd would favour the radionuclides remaining in the root zone, leading to a greater external exposure from soil, and to a greater amount of radioactivity potentially available for root uptake. On the contrary, a low Kd would favour the leaching of the root zone and the subsequent disappearance of the radionuclides from this compartment, reducing the external exposure from soil, and the quantity of radionuclides available for root uptake. Consequently, a high Kd may lead to an increase in the final dose if the radionuclide remains available for uptake in the food chain pathways.

**$TF_{soil/plant,I}$**

— Nature of the estimate: single value, qualified as best estimate; it is assumed for the illustrative purpose that the IAEA/IUR report (IAEA, 1994) (as an example of already existing data source) and the results of the elicitation exercise (Sumerling, 1992) (as a way to include the recourse to elicitation procedures) are relevant references. Due to the assessment philosophy, the median of the confidence interval is assumed to be the value of interest when interpreting the elicited confidence intervals of Sumerling (1992). This reference did not consider such a selection of single values.

— Consequence of correlations: due to the existing correlation between Kd and $TF_{soil/plant}$, it is unlikely that a high Kd would be associated to a high $TF_{soil/plant}$, except if it included the external contamination of the edible part of the plant.

— Consequences attached to extreme outcomes: a high soil-to-plant transfer factor increases the amount in radioactivity in the plant leading to a greater dose due to ingestion. To some extent, it has also an influence on the depletion of radionuclides in the root zone.

(4) *Encoding*

**$Kd_I$**

— For sandy soils, the IAEA/IUR document (IAEA, 1994) gives a range of 1.3 $10^{-5}$ to 8.5 $10^{-2}$ $m^3$ $kg^{-1}$, and an expected value of $10^{-3}$ $m^3$ $kg^{-1}$. The elicitation exercise (Sumerling, 1992) did not differentiate the soil types but addressed local conditions around a specific site, which lead to a 95% confidence interval from $10^{-1}$ to 3 $10^3$ $m^3$ $kg^{-1}$, with a median around 3 $10^2$ $m^3$ $kg^{-1}$.

— Consistency with existing correlations: due to the correlation between Kd and $TF_{soil/plant}$, and the consequences associated to the extreme outcomes (see conditioning), it is physically difficult to combine a high Kd and a high $TF_{soil/plant}$. For this reason, best estimates are appropriate, i.e. $10^{-3}$ $m^3kg^{-1}$ from (IAEA, 1994) and 3 $10^2$ $m^3kg^{-1}$ from (Sumerling, 1992).

**$TF_{soil/plant, I}$**

— For grass, and translated to fresh weight, the IAEA/IUR document (IAEA, 1994) gives a 95% range from 3.4 $10^{-5}$ to 3.4 $10^{-3}$, and an expected value of 3.4 $10^{-4}$ (dimensionless). The elicitation exercise (Sumerling, 1992), accounting for local conditions around a specific site, led to a 95% confidence interval of 3 $10^{-4}$ to 1.6 $10^{-1}$, with a median of $10^{-2}$.

— Consistency with existing correlations: due to the correlation between Kd and $TF_{soil/plant}$, and the consequences associated to the extreme outcomes (see conditioning), it is physically difficult to combine a high Kd and a high $TF_{soil/plant}$. For this reason, best estimates are appropriate, i.e. 3.4 $10^{-4}$ from (IAEA, 1994) and $10^{-2}$ from (Sumerling, 1992).

(5) *Formal output format*

**$Kd_I$**

- Determination of the sorption coefficient in soil for iodine, expressed in $m^3\ kg^{-1}$.
- The organic content of soil is a source of uncertainty; the soil type is a source of variability and uncertainty. The identity of the isotope does not appear as a source of variability.
- It is possible that soil-plant transfer may be negatively correlated with sorption coefficient. Then, best estimates are evaluated rather than cautious values.
- It is assumed that equilibrium between soil solid and liquid fractions is established; the soil type is set sandy in the current exercise and homogeneous through the root zone. The organic content is not known.
- $Kd_I = 10^{-3}\ m^3kg^{-1}$ according to the IAEA/IUR report (IAEA, 1994); and $Kd_I = 3\ 10^2\ m^3kg^{-1}$ according to the elicitation exercise (Sumerling, 1992). In the current study it is not straightforward to explain the apparent discrepancies found between (IAEA, 1994) and (Sumerling, 1992). The search for such an explanation would require extra information which is not readily available.

**$TF_{soil/plant,I}$**

- Determination of the soil-to-plant transfer factor for iodine, dimensionless.
- The plant type is a source of variability and uncertainty, and the climate conditions too; the soil type is a source of uncertainty. The feature fresh or dry weight is a source of confusion which is avoided by checking carefully the dimension equations.
- It is possible that soil-plant transfer may be negatively correlated with sorption coefficient. Then, best estimates are evaluated rather than cautious values.
- Fresh weight in plant is assumed; uniform nuclide distribution through the root zone; the quantity is averaged over one full year including seasonal variations, and averaged over a number of successive years for given climate conditions, which are taken as temperate for the current exercise. Plant type is assumed as pasture like.
- $TF_{soil/plant,I} = 3.4\ 10^{-4}$ (dimensionless) according to the IAEA/IUR report (IAEA, 1994); and $TF_{soil/plant,I} = 10^{-2}$ (dimensionless) according to the elicitation exercise (Sumerling, 1992). In the current study it is not straightforward to explain the apparent discrepancies found between (IAEA, 1994) and (Sumerling, 1992). The search for such an explanation would require extra information which is not readily available.

As a conclusion to this sub-section, emphasis should be put on the fact that even if these examples have shown that the data protocol is applicable to various data types that are important when studying the biosphere component of the safety assessments, one should be very careful when trying to extrapolate these illustrations to other contexts. Indeed, such an attempt should not be performed directly from the results of the illustrations, but should rather start from a real iteration of the data protocol, so as to check any assumptions and explain and document any decision.

It is also the case that some types of data required for assessments are less amenable to scientific review or confirmation, e.g. future food consumption habits. Drinking water consumption was evaluated in BIOMASS Theme 1, according to the full protocol (see Example 1 in Part C). Other consumption data have been used in the Reference Biosphere Examples taking account of the following comparisons of habit survey data.

### BIII–3.3.3. Comparison of consumption databases

Initial consideration of the consumption rate databases for the Example Reference Biosphere calculations was based on the data presented by Robinson (1996). Alternatives to Robinson exist for temperate climate conditions, which were identified. The databases are:

- Spanish survey (MAPA, 1993);
- Central Hungary (Thorne, 2000);
- IAEA (1995);
- IAEA (1996);
- USDA (1998).

Water consumption data have been taken from BIOMASS Example Reference Biosphere 1 (Part C).

A great deal depends on the type of original data. It is often impractical for large-sample food consumption surveys to run for long periods of time. The Robinson (1996) database is derived from a survey of 2197 individuals over one week. From these data the annual averages are derived. Other surveys e.g. USDA (1998), used to derive consumption habits for rural inhabitants of the Western USA, are based on one- and two-day habit surveys. 1271 individuals are in this dataset, a subset of a USA-wide survey.

Obviously the timescale of sampling influences the way in which the results may be used when annual averages are required. The other published results used here are presented as annual averages although details of the sampling are not known. (IAEA, 1996) presents results as daily averages. Often large sample sizes have been employed (IAEA, 1996) and in such cases ergodicity may be invoked to support the generation of annualised values even when the sampling has taken place over relatively short timescales. However this technique is more properly applied to the mean of the distribution than to the extreme percentiles.

The first four of the surveys listed above were of populations in climate zones closely identifiable with the ZB VII Zonobiome of Example Reference Biosphere 2. None of the surveys provided all the data of interest to the Example. The Robinson (1996) survey, orientated towards supporting radiological assessments, was based on a nationwide sample of the UK population. The database USDA (1998) survey, used by Kessler and Kłos (1998) is included for comparison of results from a population inhabiting the western USA, classified as desert, with hot, arid conditions. It is interesting to compare the data for consumption of the various ingestion exposure pathways derived from the different surveys, bearing in mind the different climate, agricultural and social factors.

A problem encountered in trying to apply data from different databases is that there is no absolute classification scheme employed. Thorne (2000) illustrates how survey data results over a broad array of pathways can be aggregated for assessment purposes. In the comparison which follows, summarised in Figure BIII–5, the results have been aggregated to match the exposure pathways relevant to Example Reference Biosphere 2.

In Figure BIII–5, the consumption rates for cereal, root vegetables, total meat (beef, pork, lamb, poultry and game), milk and dairy products, green vegetables, total fruit (citrus, berry fruit, stone fruit), egg, fish and drinking water are compared. Plotted values correspond to quoted values – the mean annual consumption rates. The Robinson data (Robinson, 1996) are the median values.

The first four foodstuffs in Figure BIII–5 make up the bulk of most diets and the survey results show little variation, mostly indicating consumption within a range of a factor of three. However, doses to particular exposure groups may be dominated by consumption of relatively small quantities of foods which do not play a major role in the diet, because they may contain higher concentrations of radionuclides. Greater variation is seen in survey results for these other foods. Nevertheless, these data, in combination with the observation that, the upper percentiles (95 - 97.5) of consumption of any particular food are about a factor of three higher than the median (Byrom et al., 1995), help to scope the range of uncertainties associated with assumptions for consumption data.

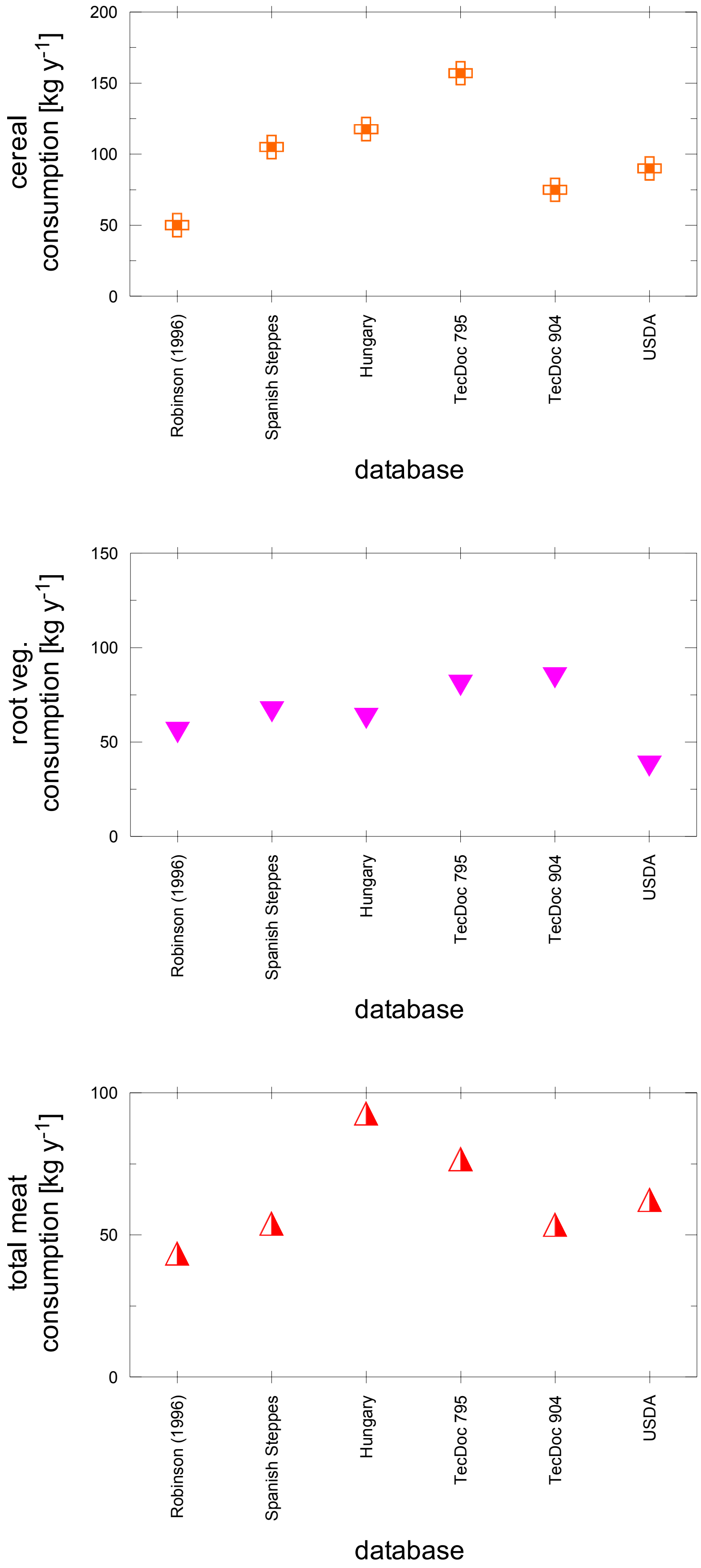



*FIG. BIII–5. Comparison of recent food consumption databases.*

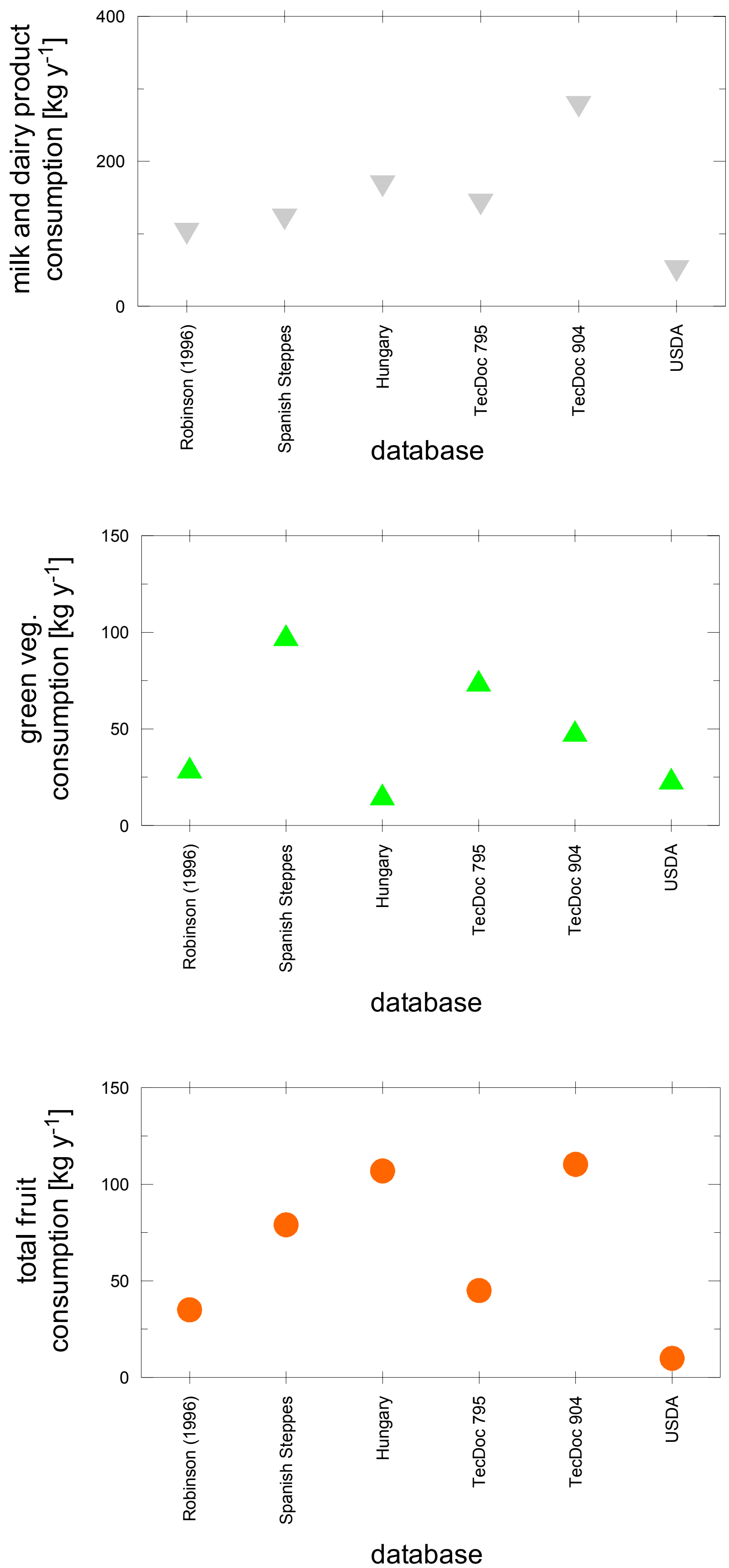
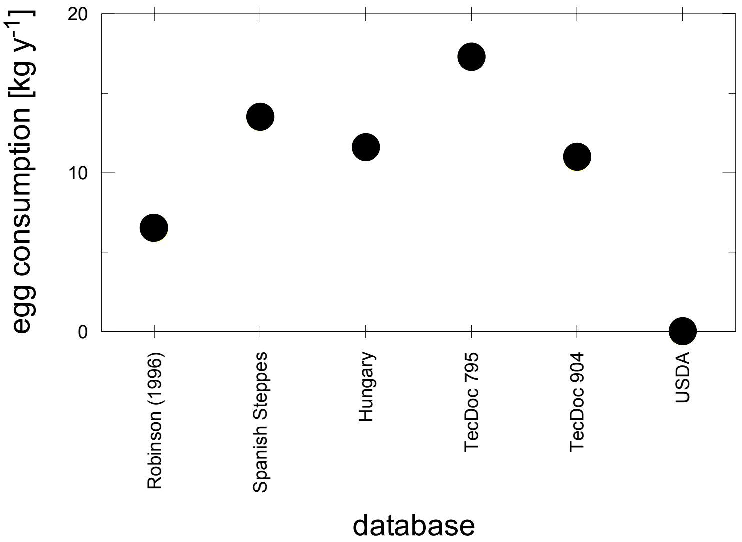
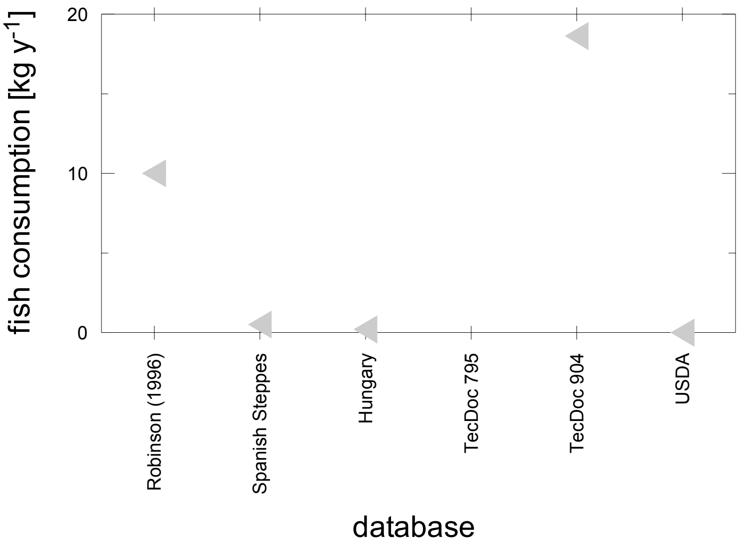



*FIG. BIII–5. Comparison of recent food consumption databases (continued).*



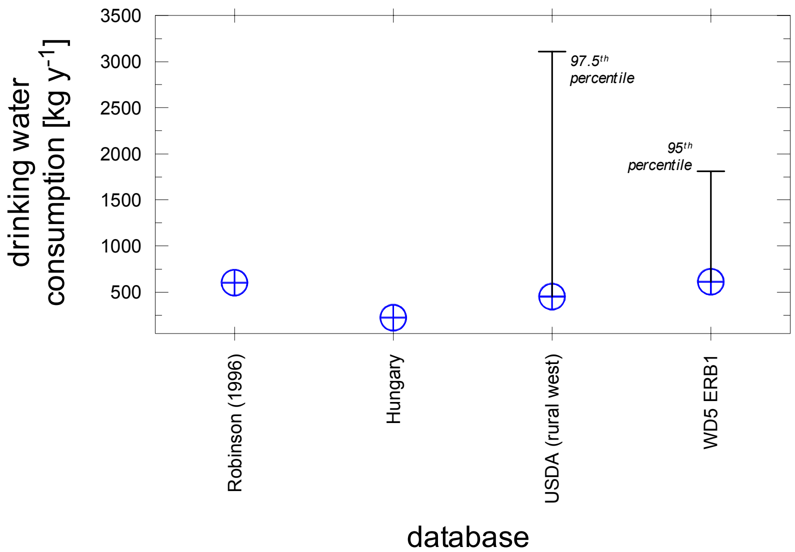




*FIG. BIII–5. Comparison of recent food consumption databases (continued).*

## BIII–4. GUIDANCE ON DATA SELECTION IN THE OVERALL BIOMASS METHODOLOGY: PARTICULAR ISSUES

### BIII–4.1. THE PROBLEM OF REPRESENTATIVE SYSTEM SELECTION

At an early stage in the BIOMASS Methodology it is necessary to identify and justify the biosphere system(s) to be analysed in the assessment. The system(s) identified must adequately respond to the information contained in the assessment context (purpose, endpoints, philosophy etc). But from this information it will not usually be obvious how narrowly to define the system. If, for example, the requirement were to consider a Tundra environment, would it be necessary to distinguish the different types of Tundra that exist in different places? The Tables of Annex BI are designed to help with this problem. However, experience may show that it is difficult to quantify relevant fixed features, and it may be necessary to recognise that specific climate states are in reality points of a continuum of climate changes. The approach to using information to deal with a changing climate (or other features of the system) is discussed in Section B3.1 of the main text of Part B.

Annex BV to this part (Part B) provides some generic data and discusses correlations between biosphere systems components and characteristics.

### BIII–4.2. THE DATA SELECTION

Among several current analogues for one given situation, one question is to know how it is possible to select/extract and average relevant data. For example, is it possible to analyse and synthesise the tundra analogues in North America/ Europe/ Asia?

### BIII–4.3. ANALYSIS OF DATA RELATED TO THE SYSTEM DESCRIPTION

For the methodology components “critical groups” and “justification of biosphere systems” the experts have to make the initial choice of relevant parameters and data to enable the description (and differentiation) of the biosphere systems selected. After this step, the aim is to ensure that the data selected are consistent with the initial purpose. This consistency should be tested in the introduction to the data protocol, when taking into account the “other components” of the BIOMASS Methodology and the available information.

### BIII–4.4. DATA GATHERING

Besides the set of data required for clearly describing the systems, there are those data necessary for performing the calculations. Here all the discussions related to data availability, data selection, data extrapolation, data base construction and use, relations between data and time frame etc. are relevant.

### BIII–4.5. FOCUS FOR FURTHER STUDIES (REVIEW AND EXPERIMENTS) ON CRITICAL ISSUES

In some areas, the description of biosphere systems and the associated modelling is weakened by a poor level of phenomenological understanding. The importance of improving this knowledge relies heavily on expert judgement, but some elements of information can be obtained through formal techniques like sensitivity analyses. At present, some fields have already been identified as critical issues, such as the treatment of interception by plants, and their interactions with irrigation (Part C).

### BIII–4.6. THE ISSUE RELATED TO THE SIZE OF THE CRITICAL OR OTHER EXPOSURE GROUPS

This issue leads to questions about the levels of description and interpretation of usual socio-economical data for quantitatively describing the critical group (e.g. difficulty in obtaining representative data for a single farm system, ease of gathering national averages). The age structure of the critical group could also be considered for some types of exposure, even if it is not a prominent factor in the case of chronic exposure through the entire life.

Factors lying outside the biosphere model must be considered, such as the water availability given by the geosphere model at its interface with the biosphere. That is, the water supply must be sufficient for the exposure groups.

### BIII–4.7. LEVEL OF TECHNOLOGY

According to the choice, this steers the consideration of either historical data (20$^{th}$ century habits for instance) with the associated typical difficulties (initial purpose for collation of original data compared with the current reason), or current data (with more flexibility for their analyses). It is driven by the assessment context under the societal assumptions topic.

### BIII–4.8. DISCUSSION ABOUT THE ACTUAL LEVEL OF DETAIL REQUIRED

Studies such as sensitivity analyses can help to lessen the importance of some features (diets for example) and increase the fundamental ones (level of autarchy). This kind of discussion can only be performed *a posteriori*, requiring multiple iterations. More generally, one should avoid spurious complexity (e.g. distinguish too many types of plants, but instead consider major types rather than single species: leafy vegetables, fruit vegetables, roots etc. instead of lettuce, spinach etc.). It is necessary to be consistent with the overall level of detail adopted, whatever the biosphere components. However, it is assumed that such categories are justified, not only by their final use (modelling for performance assessment) but also by the initial origin of the data (e.g. actual data from experiments).

## BIII–5. CONCLUSIONS

Due to the difficulties associated with the management of data, whether it is their production and the control of their uncertainties, or the selection of parameter values along with the development of models, it is not possible to consider this issue as a mere sequential step in the safety assessment procedures. Rather, all the topics that are associated with the application of data to assessment models lie at the cross-roads of several technical fields, and in the particular area of biosphere modelling, they depend also on interactions with the other components of the BIOMASS Methodology.

For these reasons, data management should be considered from the beginning of any safety assessment exercise, especially due to the influence it can have on modelling developments and because it can be resource consuming. Its treatment should be explicit and properly documented, trying to avoid confusion and potential loss of information. Data management should interact strongly with other components of the BIOMASS Methodology as an element of an integrated process which depends on various assumptions (especially from the safety assessment context) and which can influence in return these other components (e.g. owing to the data availability). Consequently, the treatment of data should certainly involve discussions with experts who have different backgrounds, in order to avoid bias and to benefit from synergies.

The construction and implementation of a protocol for the derivation of data is important to demonstrate rigour in the overall data management. The main steps identified in developing such a protocol have been identified as:

- an introduction, as a way to take into account the assessment context and other external constraints, and to list the easily available information;
- the structuring of information, so as to define properly the quantities under scrutiny and to review the scientific and technical aspects which can govern their determination;
- conditioning, which is a step where qualitative decisions are taken in order to adapt the previous knowledge to specific studies;
- encoding, which is the step where quantitative decisions are expressed, leading to the determination of data in its strict sense;
- adoption of a formal output format, essential for enabling traceability and communication.

The protocol for the derivation of data demonstrates the advantages embodied in any structured approach: it should be documented, leading to its understanding even by people who would not have been directly involved in its implementation; it should be traceable, allowing the performance of multiple iterations when updates are required; and it should be defensible. Last but not least, the data protocol has been demonstrated to be applicable and adaptable to the biosphere realm by its application to illustrative examples.

The multiple steps that compose the data protocol should not be perceived as a burden preventing the adoption of the common simplifications that have been developed through experience. The protocol can be greatly simplified when regulations clearly impose data choices, when there is a consensus for justifying simplicity, when a certain level of technical arbitrariness is adopted (e.g. through the modelling of highly stylised situations), or when some parameters are known to be of minor importance in the biosphere assessment (through sensitivity analyses). The requirement remains to document such decisions and the rationales which support them.

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# ANNEX BIV
# GENERIC FEP LIST FOR BIOSPHERE ASSESSMENT MODELLING

## BIV–1. FEP LIST STRUCTURE

A structured generic Biosphere FEP list was developed during BIOMOVS II project by the Reference Biospheres Working Group (SSI, 1996). The BIOMOVS II FEP list was developed specifically for application to the calculation of annual individual doses arising at an inland site from long-term releases of radionuclides in groundwater. It was recognised that the list did not include sufficient detail to be able to address all possible assessment contexts of interest to biosphere assessment.

One of the aims in developing the BIOMOVS II FEP list was to adopt a logical structure, which would facilitate systematic screening and, where necessary, more readily enable subsequent development and augmentation (SSI, 1996). Various approaches to the development of such a structure are possible; ultimately, however, the primary requirement is that the logic should assist model development. The extent to which increasing detail needs to be explored within the FEP list is a matter of judgement – good supporting documentation may enable specific examples of a particular FEP to be identified as part of the definition, rather than pursuing the structure of the list to a lower level. This would be the case, for example, where there are a large number of potential members of a particular group (such as types of flora relevant to natural ecosystems), and there is no perceived need to identify all possible examples.

Since the original International Biosphere FEP list was developed, renewed attention has been given within BIOMASS to different aspects of the BIOMASS Methodology. Consequently, certain changes have been made to the organisation of the BIOMOVS II list in order to reflect the following developments:

— A clearer distinction between 'FEPs' related to basic elements of the assessment context and those related to the biosphere system, radionuclide transport and radiation exposure.
— The expression of intrinsic phenomena relating to the biosphere system in terms of characteristics of the system, rather than the behaviour of radionuclides within the system. Those FEPs that relate to radionuclide behaviour can (where necessary) be incorporated in the respective definitions. FEPs that are related solely to the presence of radionuclides within the system (e.g. radiation exposures) are then clearly identified under a separate heading.
— Experience gained with the application of the Reference Biosphere Methodology since BIOMOVS II (see e.g. (EPRI, 1996)), which has helped to amplify certain details of the original list and led to the incorporation of additional FEPs.

It is worth noting that 'properties' of environmental media (e.g. size, colour, permeability, porosity etc.) are not addressed within this FEP list; such properties are more properly reflected in the characterisation of biosphere components as part of the system description. Hence the 'features' included in the FEP list are not characteristics of the components of the system, but an identification of the components themselves. Properties that are identified as being relevant to providing a comprehensive description of the stylised biosphere system are then characterised through the selection of, and assignment of quantitative values to, parameters used in mathematical models.

The FEP list is not a static document; it can evolve both in terms of the breadth of its coverage (e.g. to include coastal or marine, as well as terrestrial environments) and according to improved scientific understanding of FEPs that govern the significance of radionuclide behaviour in the biosphere. One approach for reviewing and updating the FEP list is to ensure that each of the phenomena associated with the biosphere system description developed for a particular assessment context can be linked to one or more FEPs. When the FEP list is used as an audit tool for biosphere models, it should also be reviewed (and updated, if necessary) to ensure that it matches current scientific understanding.

## BIV–2. FEP LIST CONTENTS

In what follows, the individual items in the FEP list are expanded to provide definitions of each FEP and, where appropriate, comments (in *italics*) on the role of FEPs in biosphere model development. The numbering reflects the hierarchy of the FEP.

### BIV–2.1. ASSESSMENT CONTEXT

| |
|---|
| The circumstances in which a biosphere model is to be developed and used. |

*The context in which a biosphere assessment is performed can have an important bearing on how the various environmental features, events and processes that are of potential importance are addressed in a specific assessment.*

#### BIV–2.1.1. Assessment purpose

| |
|---|
| The underlying reason for developing a biosphere model and/or carrying out a biosphere assessment. Example assessment purposes include:<br><br>Demonstration of compliance with regulatory requirements<br>Formulation of regulatory guidance<br>Contribution to public confidence<br>Contribution to confidence of policy makers and the scientific community<br>Guide research priorities<br>Proof of concept<br>Guide to site selection and approval at later stages in repository development<br>System optimisation. |

*Biosphere models are typically used as tools to determine the significance of potential future discharges from waste disposal facilities. However, in any specific case, the purpose of developing and/or applying a model may vary from a simple calculation (e.g. to support concept development) to a detailed site-specific performance assessment in support of a disposal licence application.*

#### BIV–2.1.2. Assessment endpoints

| |
|---|
| The required format of the assessment results, expressed as a calculated radiological impact or in other terms. |

*The structure of a model will tend to reflect the results that it is designed to evaluate. These, in turn, will largely depend on the criteria (regulatory or otherwise) that are adopted to judge the performance of the disposal system, of which the biosphere is a part.*

*BIV–2.1.2.1. Annual individual dose*

| |
|---|
| The radiation dose to a person, incurred over a year (usually taken to mean the committed dose from exposure over a year). |

*The exposed individual must be defined. In waste disposal assessments, the calculation of individual dose is based on the assumption of a hypothetical 'representative' individual, designed to demonstrate that adequate radiation protection is afforded to future populations. Modelling approaches may differ according to whether the endpoint is intended to be the maximum potential dose in <u>any</u> year, or the annual dose averaged over a lifetime's exposure.*

*BIV–2.1.2.2. Lifetime individual dose*

| |
|---|
| The radiation dose to a person, accumulated over their lifetime. |

*This may potentially present fewer difficulties than the evaluation of annual dose, since it explicitly requires averaging over year-on-year variabilities in factors controlling environmental concentrations of radionuclides.*

*BIV–2.1.2.3. Annual individual risk*

| |
|---|
| The radiological risk to a person, averaged over a year. |

*Again, the exposed individual must be defined. (Further discussion is provided in BIOMASS (1999b).) Risk considerations also raise the question of how biosphere assessment calculations should be conducted – for example, whether uncertainty in certain parameter values chosen to represent the biosphere system should be expressed in terms of probability distribution functions.*

*BIV–2.1.2.4. Lifetime individual risk*

| |
|---|
| The radiological risk to a person, accumulated over their lifetime. |

*Risk criteria are more regularly expressed in terms of annualised risk for ease of comparison with other risks from human activity – and hence to establish levels of tolerability. Moreover, dose-to-risk conversion factors vary with age at the time of exposure, presenting potential integration difficulties.*

*BIV–2.1.2.5. Collective dose/risk*

| |
|---|
| The radiation dose or radiological risk integrated over an exposed population. |

*The calculation of collective dose (or risk) is critically related to the assumed size of the exposed population and the timescale over which integration is carried out, which should be* *defined as part of the basis of the calculation. It can be appropriate to limits to truncate both the timescale and the lower levels of individual exposure included in the evaluation of collective dose.*

*BIV–2.1.2.6. Dose to non-human biota*

| |
|---|
| The radiation dose to organisms other than man. |

*There remains uncertainty regarding how best to demonstrate compliance with the basic safety principle of assuring environmental protection. Some authorities are considering qualitative requirements on non-human impacts, but few have yet developed quantitative criteria. However, it is not unreasonable to consider that assessments of dose to a variety of species types might provide insight into the potential damage to the environment.*

*BIV–2.1.2.7. Modification of the radiation environment*

| |
|---|
| The concentration and/or distribution of repository-derived radionuclides in environmental media. |

*The evaluation of radiological exposures has increasingly less meaning for assessment calculations extending over very long timescales. Relevant comparisons could include comparisons with natural background sources and concentrations in environmental media. Estimates are less dependent on seemingly arbitrary assumptions about human behaviour but correspondingly less indicative of the impact on human health. A particular consideration is the assumed spatial extent over which the endpoints should be evaluated – averaging approaches invoked in models designed to determine radiological exposure are not necessarily appropriate to the determination of representative concentrations in environmental media.*

*BIV–2.1.2.8. Fluxes*

| |
|---|
| The release rate of radionuclides into, or through, parts of the biosphere. |

*There may be no direct requirement to evaluate the migration and accumulation of radionuclides; however, there is still a need to consider the interactions between geosphere and biosphere systems.*

*BIV–2.1.2.9. Non-radiological endpoints*

| |
|---|
| Biospheric consequences of disposal unrelated to radioactivity. |

*Biosphere assessments may not only need to address radiological endpoints but also, for example, the dispersion and consequences of the release of other pollutants from the repository.*

*BIV–2.1.2.10. Uncertainties and/or confidence*

| |
|---|
| An estimate of the confidence that can be attached to the quantitative value of a given endpoint. |

*This is strictly just one aspect of a given endpoint, rather than an endpoint in itself. However, there may be a specific requirement to evaluate confidence in the estimated values of particular quantities, such as dose, separately from the assessed likelihood that the circumstances giving rise to the dose will happen.*

### BIV–2.1.3. Assessment philosophy

| |
|---|
| The underlying approach adopted towards the management of uncertainties within the assessment. |

*Whereas the nature of the assessment endpoints may be clearly defined, the nature of the assumptions used within the assessment also needs to be made clear. A particularly important example concerns the degree of pessimism introduced by assumptions regarding spatial and temporal averaging in the determination of radiological exposures. If possible, consistency should be sought between the philosophy underlying the derivation of (say) regulatory criteria and that adopted in calculations geared towards demonstrating compliance with such criteria.*

### BIV–2.1.4. Repository system

| |
|---|
| The type of disposal facility to be addressed in the assessment calculation. |

*The description of the process system to be represented in a biosphere assessment model must be consistent with the known details of the disposal facility being considered, including the type of repository under consideration. For example, the type of repository (characterised by depth, waste type, host rock etc.), in conjunction with other aspects of the assessment context (such as the site context and evolution of future climate), can support identification of radionuclides of concern, or the geosphere/biosphere interface(s).*

### BIV–2.1.5. Site context

| |
|---|
| A 'broad-brush' description of the physical features of the present-day biosphere in the general location where future releases may occur. |

*The general location of a repository may have an important influence on the likely pathways for release of radionuclides to the biosphere and the extent to which factors such as climate and ecological change can influence the impact of such releases. For example, a coastal location may provide a marine receptor for radionuclides released from the repository, whereas the assessment for an inland mountain location may not need to address marine FEPs. Additionally, site context should define, in general terms, the current surface topography and climate in the vicinity of the site. For example, the topography at some sites may suggest lacustrine environments whereas, in others, lakes are not common.*

### BIV–2.1.6. Source term

The release of contamination into the biosphere from the repository system.

*Biosphere models are typically decoupled, to a greater or lesser extent, from those models that are used to evaluate the release of radionuclides from the waste repository and transport through the geosphere. The link to the biosphere in such a decoupled system is described as the 'source term'. A full description of the source term involves giving consideration to the boundary interface across which the link between models is established, which in turn is partly dependent on the release mechanism, and the characteristics of the release itself, expressed in terms of its content and properties. Modelling requirement for some radionuclides will be very different from others.*

#### *BIV–2.1.6.1. Geosphere/biosphere interface*

The interface between biosphere and geosphere domains in a decoupled system model.

*The geosphere/biosphere interface defines the border of the biosphere model domain at its boundary with the geosphere. Definition of the interface is an intrinsic part of conceptual modelling, because the division of the repository environment into biosphere and geosphere domains is itself part of the conceptual approach. The interface should properly be located where decoupling of the models is possible, which is effectively to say that it should be positioned where recirculation of radionuclides (or other contaminants) across the boundary is insignificant in terms of the overall contamination of the environment. Ideally, the domain of a biosphere model should be such that it can address various potential release mechanisms. In practice, an internally consistent identification of the interface will be obtained if both the biosphere and geosphere assessment models are informed by the same regional hydrological model. Except for simple well-water extraction scenarios, the detailed configuration and characteristics of the interface between the biosphere and geosphere is likely to be site specific and may be time dependent.*

#### *BIV–2.1.6.2. Release mechanism*

The mechanism for transferring radionuclides (and other contaminants) from the geosphere to the biosphere. Example release mechanisms include:

Groundwater release to land and surface water bodies via natural aquifer discharge
Groundwater release via extraction of well water
Gaseous release
Release of solid materials as a result of human intrusion or natural erosion.

*Consideration of different potential mechanisms for releasing radionuclides to the biosphere is an intrinsic part of the process of model definition, contributing to consideration of the geosphere/biosphere interface, the physical and chemical form of the release and the temporal and spatial distribution of the release.*

#### *BIV–2.1.6.3. Source term characteristics*

Basic attributes of the source term from the geosphere to the biosphere, including:

Radionuclide and other hazardous materials content
Physical and chemical properties of the release.

*Characterisation of the source term is important in order to ensure that model definition adequately addresses the specific properties of the release, for example in terms of the behaviour of particular chemical elements.*

**BIV–2.1.7. Time frames**

Identification of the time period for which biosphere modelling is required.

*The selection of a specific time frame can have considerable impact on considerations related to biosphere modelling, including the treatment of site evolution, critical radionuclides and geosphere/biosphere interfaces.*

**BIV–2.1.8. Societal assumptions**

Broad hypotheses regarding the way in which representative future biospheres are presumed to be exploited by man.

*Human activities have a major influence on the status of the environment. The definition of future biosphere systems will therefore involve implicit or explicit hypotheses concerning social-economic structures (e.g. industrial, agrarian), land use, technological development etc. Such hypotheses will influence both the definition of the biosphere system and the assumed behaviour of potential exposure groups.*

BIV–2.2. BIOSPHERE SYSTEM FEATURES

A description of the biosphere system(s) assumed to be representative of future environmental conditions at the site(s) of interest.

*Definition of the main features of the assumed biosphere system involves characterising ecological systems and human communities, consistent with possible climatological changes and landform developments that may be relevant over the timescales of the assessment.*

**BIV–2.2.1. Climate**

A description of the way in which climate is represented in the biosphere assessment.

*The treatment of climate in characterising the future biosphere systems may range from the assumption of constant present-day conditions to a full simulation of continuously-varying climate successions. The choices made in respect of modelling climate (and its effects on the biosphere system) can have a strong influence on the overall structure and composition of the biosphere model.*

*BIV–2.2.1.1. Description of climate change*

| |
|---|
| The approach taken to considering the potential impact of changing climate. |

*There are various possible approaches to representing the effects of climate change within a biosphere assessment. At a very basic level, climate change might be ignored and the assessment based on the assumption that current conditions persist indefinitely into the future. Alternatively, there is the option of modelling the release into any one of a variety of time-invariant biospheres, each of which is consistent with the chosen set of representative climate states. Time sequences of transition between climate states may be considered to represent a more realistic approach, but there is substantial scientific uncertainty concerning the future sequence of climate development, especially when the possible long-term effects of anthropogenic "greenhouse-gas" emissions are taken into account. Moreover, the treatment of time lags and leads in addressing the relationship between climate and landform or ecological transitions is also subject to considerable scientific uncertainty. The approach taken in practice will depend, in part, on the overall assessment philosophy with respect to the management of uncertainty, and the extent to which this is prescribed by the way in which regulatory criteria are interpreted.*

*BIV–2.2.1.2. Identification and characterisation of climate categories*

| |
|---|
| The identification and general description of characteristic climate states relevant to the assessment. Relevant characteristics include temperature, precipitation, wind speed and direction and solar radiation. |

*If climate change (rather than a constant present-day climate) is addressed as part of the overall assessment basis, the assumption is often made that the range of future climate states relevant to the site of interest can be broadly characterised in terms of a number of discrete climate states. The identification and definition of such states should be based on a coherent scheme that does not exceed the limits of scientific understanding. Given the assessment context, the identification of a particular climate scheme will involve consideration of the latitude, longitude, altitude and aspect of the region of interest, taking account of best understanding of the relevant factors determining global climate. Characterisation of climate states would be expected rely predominantly on accepted classification schemes, including diurnal, seasonal and other variations in the primary climate parameters.*

**BIV–2.2.2. Human society**

| |
|---|
| A description of the role of human actions in defining the local biosphere. Principal features of human society relevant to the description of the biosphere system include:<br><br>Community structures that determine human influence on the environment (e.g. through industry, agriculture, urbanisation)<br>The exploitation of biosphere resources (e.g. water bodies, land, natural flora and fauna)<br>The extent of import and export of resources to/from the domain of the biosphere system. |

*A coherent description of human society should be adopted, consistent with other assumptions regarding climate, landscape and ecology, and taking account of the overall socio-economic context assumed as a basis for assessment.*

#### BIV–2.2.3. Systems of exchange

| |
|---|
| The identification of environmental systems and their arrangement in the landscape. |

*The main features of the biosphere system can be described in terms of large scale environment 'types', within which specific ecosystems are identified. This, in turn, leads to the description of the biosphere in terms of communities of plants, animals and microbes, together with the physical environment that they inhabit. Such communities typically consist of complex arrangement of relationships and dependencies, ultimately reaching quasi-equilibrium at a given successional stage. However, the equilibrium that is achieved may be very sensitive to external events and processes; in particular, the intervention of Man can dramatically influence the natural progression of ecosystems, for example through agricultural practices. Over the long periods of time generally associated with safety assessments for the disposal of solid wastes, the range of possible future situations in the biosphere is very wide. Because of this wide range of possibilities, and the uncertainties associated with future human actions, biosphere systems adopted for the purpose of assessing potential radiological impact are best considered as contributing to representative indicators of performance, rather than as definitive predictions of future environmental conditions.*

*BIV–2.2.3.1. Environment types*

| |
|---|
| Identification and description of features of the landscape to be addressed in the biosphere assessment. |

*The basic identification of environment types is broadly related to the assumed extent of the influence of human actions. The type of environment has an important influence on the way in which specific ecosystems may develop and on their configuration in the landscape.*

***BIV–2.2.3.1.1. Natural and semi-natural environments***

| |
|---|
| Environments that are not significantly, or are only partially, influenced by human activities. |

*If a 'natural' environment is a true wilderness, then the absence of people means that any evaluation of radiological impact for humans is largely meaningless. However, it is possible to conceive of situations in which the radiological impacts on species other than man may be important. Moreover, radiological impacts to humans may arise following the disturbance of a previously contaminated natural environment. It is also possible to identify regions where humans have access but within which the natural biogeochemical cycles are largely unaltered. Such environments might include, for example, undeveloped marshland, natural forest, heather moorland and alpine meadows. In the context of biosphere assessment, the primary distinctions between these and other classes of environment are therefore: (i) human influences are small; and (ii) exposure pathways for humans will tend to be based on the exploitation of natural resources.*

***BIV–2.2.3.1.2. Agricultural environments***

Terrestrial regions intensively exploited for food as pasture and arable land.

*The intensity of land use will vary according to primary productivity, as well being changed by the introduction of cultivation methods and nutrients that alter the natural biogeochemical cycle. Different levels of intensification can be identified from contemporary agricultural practice in different climate conditions around the world; these will typically form the basis for assumptions regarding the definition of an agricultural environment appropriate to the site under consideration.*

***BIV–2.2.3.1.3. Urban and industrial environments***

Environments exploited by humans in which habits, diet and exposure are significantly different from the agricultural environment.

*The degree of industrialisation in a society has a marked effect on the extent to which humans have an influence on their environment, rather than allowing natural processes to determine the dynamic evolution of the biosphere. There may be a limited measure of self-sufficiency in urban environments (gardens etc.), but a major element of such 'systems' is the extent to which foodstuffs and other materials are transported from distant regions. In addition to its impact on flora and fauna, human activity in urban and industrial environments can lead to major changes to the natural topography and hydrogeochemical cycles.*

*BIV–2.2.3.2. Ecosystems*

Communities of living organisms and their habitats.

*The identification of ecosystems should as far as possible be internally coherent, corresponding to the assumed hydrological regime (i.e. terrestrial, wetland or aquatic habitat) and taking account of geochemical factors (i.e. pH, salinity etc), climate and human influence. For example, a natural/semi-natural landscape may consist of a variety of ecosystems, such as forest, heather, alpine meadows, natural grassland, wetland, rivers etc. In the same way, an agricultural landscape might include, for example, pasture and arable land, fish ponds, hedges, orchards, planted forest, rivers, agricultural wells, etc. Relevant properties of ecosystems include: the physical components of the habitat (soils etc.), its spatial extent, species types and heterogeneity, the foodweb and successional characteristics.*

***BIV–2.2.3.2.1. Living components of ecosystems***

Specification of the living components of the assumed biosphere system.

*The extent to which ecosystems are broken down into specific components depends on making appropriate use of available scientific knowledge, taking account of the perceived sensitivity of the assessment endpoints of interest to the level of detail assumed. Living components of ecosystems include plants, animals and other relevant organisms (fungi, algae and microbes). Certain components will be directly relevant to the biosphere system description because of the way in which they are used by man or are otherwise important in the evaluation of assessment endpoints. These include: different types of food, whether plants (agricultural crops and/or wild* *sources), or animals and birds (domestic and/or hunted); organic materials (e.g. wood, cotton) used for construction, furniture or clothing; energy sources and animal foodstuffs.*

***BIV–2.2.3.2.2. Non-living components of ecosystems***

| |
|---|
| Specification of the non-living components of the assumed biosphere system. |

*Non-living components of ecosystems include the soil and sediment system (e.g. litter layer, top soils and deep soils), surface and subsurface water bodies (rivers and streams, estuaries, lakes, aquifers, wetlands etc.), ice sheets, above- and below-canopy atmospheres. Each of these will include, in varying proportions, solid material of mineral origin, organic matter, water and gas. Characteristics of these components – their chemical and physical properties – will have a major influence on the dynamics of the biosphere system and the distribution of trace materials. It should also be recognised that all such biosphere media will normally include both living and non-living components. Indeed, for convenience, standard descriptions of certain media (e.g. soils and sediments) sometimes include both micro- and macro-biota. In addition, certain components will be directly relevant to the assessment because of the way in which they are used by man (e.g. materials used for construction, furniture, cosmetics or clothing).*

## BIV–2.3. BIOSPHERE EVENTS AND PROCESSES

| |
|---|
| Phenomena, whether natural or artificial, that influence – or may influence – the dynamics of the biosphere system or the behaviour of trace materials in the biosphere. |

*A primary classification of processes is established in terms of whether they are of natural or human origin. It is not considered necessary to distinguish between events and processes; generally, events are regarded as short-term and processes as continuous. In practice, however, it is not unknown for events (such as rainfall or erosion) to be modelled as processes, and processes (such as environmental change) to be modelled as events.*

### BIV–2.3.1. Natural events and processes

| |
|---|
| Natural phenomena that could be involved in the dynamics of the environmental system or in the fate of trace materials. |

*The assumed biosphere system(s) will encompass a very wide range of natural phenomena at different spatial and temporal scales. Scientific knowledge and the overall context of the assessment will help to establish the degree of detail that should be adopted in representing such phenomena within the assessment model.*

*BIV–2.3.1.1. Environmental change*

| |
|---|
| Natural phenomena causing lasting change to the basic properties of the biosphere system, modifying the situation represented in the assessment. |

*Relevant changes may include modification of both biotic and abiotic features of the environment. The primary influence on long-term environmental change (Climate) is* *addressed separately at 2.1 above. Others influences include natural ecological successions and natural biogeochemical processes (e.g. soil conversion, acidification, alkalisation).*

***BIV–2.3.1.1.1. Physical changes***

| |
|---|
| Long-term physical changes in environmental media; e.g. changes in their dimensions or physical properties. |

*Natural processes such as the ageing of lakes or meandering of river courses may lead to lake or river sediments becoming land. Soil conversion and erosion caused by rainfall, surface, run-off, surface water courses and occasional flooding may give rise to gradual changes in the landscape. Climate-driven geomorphological change, such as change in sea-level, can also give rise to physical changes, such as down-cutting of river beds to new equilibrium levels.*

***BIV–2.3.1.1.2. Chemical changes***

| |
|---|
| Long-term chemical changes in environmental media. |

*Biosphere systems may not be in a state of dynamic equilibrium if, for example, the rate of evapotranspiration exceeds infiltration; the salt or alkali content of soil can then increase – with corresponding effects on ecosystems. Chemical changes may also be a result of the actions of organisms – giving rise to natural ecological successions.*

***BIV–2.3.1.1.3. Ecological changes***

| |
|---|
| Ecological successions caused by natural perturbations to the foodweb etc. |

*Natural ecological changes may take place if the ecosystem has not yet reached its climax, or if external influences (climatic episodes or other major disruptive events) affect the natural succession of communities and nutrient flows within the ecosystem.*

*BIV–2.3.1.2. Environmental dynamics*

| |
|---|
| Natural phenomena causing temporal variability in systems of exchange within an otherwise constant biosphere system. |

*A potentially important aspect of the biosphere system description is that is may vary with time according to natural cycles ranging from diurnal to decadal timescales. For example, there will be seasonality in the hydrological cycle, affecting river levels and the need for irrigation. Although the system may be treated as unchanging, it is important to ensure that parameter values are chosen carefully to reflect properly their time-averaged effect on the biosphere system.*

***BIV–2.3.1.2.1. Diurnal variability***

| |
|---|
| Cycling in properties of the biosphere system on a period of 24 hours. |

*Plant and animal behaviour patterns show strong diurnal variability, principally related to light and heat availability. Some meteorological events and processes can also be related to the diurnal cycle.*

***BIV–2.3.1.2.2. Seasonal variability***

| |
|---|
| Changes in properties of the biosphere system due to natural variability of solar radiation, temperature, precipitation, wind speed and direction through the year. |

*Factors that need to be considered in parameter selection include the effects of seasonality on food production, availability of (and requirements for) water resources, modification of the water table etc.*

***BIV–2.3.1.2.3. Interannual and longer timescale variability***

| |
|---|
| Variability in properties of the biosphere system with periodicity greater than a year. |

*Year-on-year changes in absolute seasonal temperature, precipitation and solar radiation are characteristic even of a constant climate 'state'. Such changes should somehow be addressed (either implicitly or explicitly) in the description and representation of the biosphere system. Redistributive events such as forest or heathland fire may occur periodically and are an essential cyclic feature of certain ecosystems.*

*BIV–2.3.1.3. Cycling and distribution of materials in living components*

| |
|---|
| Natural phenomena causing temporal variability in systems of exchange within an otherwise constant biosphere system. |

*Redistribution of environmental materials occurs continuously as a result of the cycling of materials in a biosphere system. Recycling processes mediated by living components of ecosystems include bulk movements of solids and liquids by flora and fauna, as well as metabolic processing of nutrients and other materials.*

***BIV–2.3.1.3.1. Transport mediated by flora and fauna***

| |
|---|
| The movement of materials within the environment caused by plants and animals. |

*Solid, gaseous and liquid phase transport of materials within the environment as a result of the natural behaviour of flora and fauna.*

BIV–2.3.1.3.1.1. Root uptake

| |
|---|
| Uptake of water and nutrients from soil solution and soil particles by absorption and biological processes within plant roots. |

BIV–2.3.1.3.1.2. Respiration

| |
|---|
| Uptake (release) of gases from (to) the atmosphere by plants. |

BIV–2.3.1.3.1.3. Transpiration

| |
|---|
| Transfer of water from the soil to the atmosphere by transpiration in plants. |

BIV–2.3.1.3.1.4. Intake by fauna

| |
|---|
| Consumption and inhalation of materials by animals, birds, fish etc., includes:<br>Food consumption (plant and animal foodstuffs)<br>Aerosol inhalation<br>Soil consumption<br>Sediment consumption |

BIV–2.3.1.3.1.5. Interception

| |
|---|
| Interception of incident rainfall, aerosol, suspended sediment etc. by plants and animal surfaces. |

BIV–2.3.1.3.1.6. Weathering

| |
|---|
| Materials captured by interception may subsequently be lost from plant and animal surfaces because of wind, rain, volatilisation etc. |

BIV–2.3.1.3.1.7. Bioturbation

| |
|---|
| The redistribution and mixing of soil or sediments by the activities of plants and burrowing animals. |

***BIV–2.3.1.3.2. Metabolism by flora and fauna***

| |
|---|
| The processes occurring within an organism by which materials are transported and accumulated through the organism or transported and liberated from the organism. |

*The internal processes will vary according to the organism and chemical elements or compounds of interest.*

BIV–2.3.1.3.2.1. Translocation

| |
|---|
| The internal movement of material from one part of a plant to another. |

BIV–2.3.1.3.2.2. Animal metabolism

| |
|---|
| The derivation and use of energy and biochemical processing of other materials from ingested substances, involving the transfer of trace materials present in animal fodder (or other ingested and inhaled material) to body tissues. |

*BIV–2.3.1.4. Cycling and distribution of materials in non-living components*

| |
|---|
| Natural processes giving rise to the movement of materials within the environment. |

*Redistribution of environmental materials occurs continuously as a result of the cycling of materials in a biosphere system. Recycling processes mediated by non-living components of ecosystems include movements of solids, gases and liquids in the atmosphere, water courses, soils and sediments.*

***BIV–2.3.1.4.1. Atmospheric transport***

| |
|---|
| Natural transport processes within the atmosphere. |

*A variety of processes linked to the atmosphere contribute to the natural movement of materials within the biosphere system.*

BIV–2.3.1.4.1.1. Evaporation

| |
|---|
| Emission of water vapour and other volatile materials from a free surface at a temperature below their boiling point. |

BIV–2.3.1.4.1.2. Gas transport

| |
|---|
| Convection and diffusion of gases and vapours in the atmosphere. |

BIV–2.3.1.4.1.3. Aerosol formation and transport

| |
|---|
| Suspension and transport of solid materials in the atmosphere, typically as a result of wind action. A special example of aerosol formation is that arising from the burning of materials in fire. |

BIV–2.3.1.4.1.4. Precipitation

| |
|---|
| Rain, snow, hail etc. as part of the natural hydrological cycle. |

BIV–2.3.1.4.1.5. Washout and wet deposition

| |
|---|
| The removal of gaseous or particulate material from the atmosphere by precipitation., causing deposition of material onto surfaces. |

BIV–2.3.1.4.1.6. Dry deposition

| |
|---|
| The removal of gaseous or particulate material from the atmosphere as a result of interception and gravitational settling. |

***BIV–2.3.1.4.2. Water-borne transport***

| |
|---|
| Natural transport processes within water courses. |

*A variety of processes associated with the hydrosphere may contribute to the natural movement of materials within the biosphere system.*

BIV–2.3.1.4.2.1. Infiltration

| |
|---|
| The downward movement of water from the surface into the soil. |

BIV–2.3.1.4.2.2. Percolation

| |
|---|
| Downward (or sub-horizontal) movement of water, with dissolved and suspended materials through soil and sediment materials towards the water table. |

BIV–2.3.1.4.2.3. Capillary rise

| |
|---|
| Upward movement of water through soil layers above the water table as a result of capillary forces related to evaporation and transpiration. |

BIV–2.3.1.4.2.4. Groundwater transport

| |
|---|
| Transport of water, with dissolved and suspended materials in saturated porous media. |

BIV–2.3.1.4.2.5. Multiphase flow

| |
|---|
| Combined flow of different fluids and/or gases in porous media. |

BIV–2.3.1.4.2.6. Surface run-off

| |
|---|
| A fraction of incident precipitation may be transferred directly from land to surface waters by overland flow, without entering the soil column. This includes delayed run-off (e.g. as a result of snow melt). |

BIV–2.3.1.4.2.7. Discharge

| |
|---|
| The release of groundwater into the surface environment. |

BIV–2.3.1.4.2.8. Recharge

| |
|---|
| The percolation of incident precipitation and other surface waters to groundwater systems. |

BIV–2.3.1.4.2.9. Transport in surface water bodies

| |
|---|
| Movement of water, dissolved and suspended materials by advection and diffusion in water bodies. |

BIV–2.3.1.4.2.10. Erosion

| |
|---|
| Erosion caused by rainfall, surface run-off, river water and occasional floods which can lead to the transport of surficial materials and plants in water courses. |

***BIV–2.3.1.4.3. Solid-phase transport***

| |
|---|
| Natural transport processes causing movements of solid materials between environmental media. |

*A variety of processes may contribute to the bulk movement of solid materials within the terrestrial and aquatic environments.*

BIV–2.3.1.4.3.1. Landslides and rock falls

| |
|---|
| Overland transport of solid material by landslides and rock falls. |

BIV–2.3.1.4.3.2. Sedimentation

| |
|---|
| Gravitational settling and deposition of suspended particles within water bodies to form sediments. |

BIV–2.3.1.4.3.3. Sediment suspension

| |
|---|
| Erosion of bed sediments from surface water courses by the action of flowing water. |

BIV–2.3.1.4.3.4. Rain splash

| |
|---|
| Localised transport of soil material to other media (e.g. onto plant) caused by the energy of incident rainfall. |

***BIV–2.3.1.4.4. Physicochemical Changes***

| |
|---|
| Chemical and physical processes causing changes to the nature of materials present within the environment. |

*Various physical and chemical processes may give rise to changes in the composition of environmental materials.*

BIV–2.3.1.4.4.1. Dissolution/precipitation

| |
|---|
| Processes by which material in the solid phases is incorporated into the liquid phase, and vice versa. Affected by local Eh, pH, solubility limits and the presence of other chemical species. |

BIV–2.3.1.4.4.2. Adsorption/desorption

| |
|---|
| Sorption and/or adhesion of a layer of ions from an aqueous solution onto a solid surface and subsequent migration into the solid matrix (and the reverse process). |

BIV–2.3.1.4.4.3. Colloid formation

| |
|---|
| Complexation of materials to form colloids. |

**BIV–2.3.2. Events and processes related to human activity**

| |
|---|
| Human activities that result in an alteration of the biosphere system and/or contribute to the cycling of materials within the system. |

*The potential human impact on the environment is an important feature of the overall biosphere system description. This may vary from major industrial development of an area to low-level changes in the natural physical and biogeochemical cycles.*

*BIV–2.3.2.1. Chemical changes*

| |
|---|
| Chemical phenomena related to human activity that can cause significant change to the biosphere system, modifying the situation represented in the assessment. |

*Human activity at global, regional and local levels needs to be taken into account in establishing the chemical environment within which a biosphere system exists.*

***BIV–2.3.2.1.1. Artificial soil fertilisation***

| |
|---|
| The import of artificial fertiliser to enhance crop productivity. |

*The use of imported fertiliser can have an impact on the cycling of trace materials in the biosphere, as well as on the overall materials budget.*

***BIV–2.3.2.1.2. Chemical pollution***

| |
|---|
| Human activities with a significant impact on the chemistry of ecosystems. |

*The existence of chemical pollution may be a contributory factor in identifying and characterising biosphere systems relevant to assessment.*

***BIV–2.3.2.1.3. Acid rain***

| |
|---|
| Acid precipitation or deposition capable of causing acidification in soil and water bodies. |

*Precursors of acid rain include emissions of sulphur dioxide and nitrogen oxides from man-made sources on a regional and local scale.*

*BIV–2.3.2.2. Physical changes*

| |
|---|
| Physical phenomena related to human activity that can cause lasting change to the biosphere system, modifying the situation represented in the assessment. |

*Human activity that affects the local landscape or otherwise changes natural transport and recycling processes within the biosphere system.*

***BIV–2.3.2.2.1. Construction***

| |
|---|
| The excavation of foundations and other structures, and building of surface features, causing gross movements of solid materials and/or changes to natural water flow patterns. |

***BIV–2.3.2.2.2. Water extraction by pumping***

| |
|---|
| Extraction of water from surface water courses of wells, causing alteration to natural water potentials. |

***BIV–2.3.2.2.3. Water recharge by pumping***

| |
|---|
| The recharge of groundwater systems by pumping. |

***BIV–2.3.2.2.4. Dam building***

| |
|---|
| The construction of engineered structures in order to retain surface waters. |

***BIV–2.3.2.2.5. Land reclamation***

| |
|---|
| The draining of areas that were formerly marshland or covered by rivers, lakes or the sea. |

*BIV–2.3.2.3. Recycling and mixing of bulk materials*

| |
|---|
| Activities that artificially enhance natural transport processes within the biosphere. |

*Human actions can result in the movement of environmental materials within the biosphere system – if people are assumed to be present, their possible contribution to the dynamics of the system should be considered.*

***BIV–2.3.2.3.1. Ploughing***

| |
|---|
| Agricultural practices enhancing the mixing of upper soil horizons. |

***BIV–2.3.2.3.2. Well supply***

| |
|---|
| Extraction and use of water from an aquifer. |

***BIV–2.3.2.3.3. Other water supply***

| |
|---|
| Abstraction of water from surface water bodies in the local biosphere. |

***BIV–2.3.2.3.4. Irrigation***

| |
|---|
| Use of abstracted water to supplement natural supplies to gardens and/or agricultural crops. |

***BIV–2.3.2.3.5. Recycling of bulk solid materials***

| |
|---|
| The re-use of crop residues, manure, ashes or sewage sludge on land in order to recycle nutrients or to act as mulch. |

***BIV–2.3.2.3.6. Artificial mixing of water bodies***

| |
|---|
| Enhanced mixing of lake and other surface waters as a direct, or indirect, effect of human actions. |

***BIV–2.3.2.3.7. Dredging***

| |
|---|
| The removal of sediments from lakes, rivers, estuaries or harbours – either to provide materials for soil improvement or simply to maintain transport channels in the water body. |

***BIV–2.3.2.3.8. Controlled ventilation***

| |
|---|
| Actions taken to enhance (or reduce) the mixing of air in enclosed spaces. |

*BIV–2.3.2.4. Redistribution of trace materials*

| |
|---|
| Activities that change the natural physical and chemical composition of biosphere products. |

***BIV–2.3.2.4.1. Water treatment***

| |
|---|
| Processing of water supplies (filtering, chemical treatment, storage, etc.) to make then suitable for drinking water or other uses. |

***BIV–2.3.2.4.2. Air filtration***

| |
|---|
| The enhanced removal of aerosols and gases from air supplies. |

***BIV–2.3.2.4.3. Food processing***

| |
|---|
| Actions taken in the preparation of foods that may modify the constituents of what is finally consumed. |

BIV–2.4. HUMAN EXPOSURE FEATURES, EVENTS AND PROCESSES

| |
|---|
| Human habits and activities involving possible radiological exposure (internal or external) from as a result of living in a contaminated environment. |

*Identification of potential exposure pathways needs to be consistent with the assumed characteristics of the biosphere system (climate, water resources, etc.), together with the underlying assumptions about human society.*

**BIV–2.4.1. Human habits**

| |
|---|
| A general description of the influences of human behaviour on exposure to contaminated materials. |

*The assumed habits of exposure groups should be consistent with assumptions concerning the inter-relationships of individuals within the local community as well as the broader social context. For example, does the community living within the biosphere system import or export materials from/to elsewhere?*

*BIV–2.4.1.1. Resource usage*

| |
|---|
| The exploitation of potentially contaminated resources (natural and other) by population groups present within the biosphere system. |

*Relevant resources include biosphere products used as foodstuffs, clothing, construction materials and energy.*

*BIV–2.4.1.1.1. Arable food resources*

Food products obtained from arable farming and/or gardening within the biosphere system. Types of product include:

- grain (wheat, rice, etc.)
- root vegetables
- leaf vegetables
- legumes
- fruit vegetables
- fruit and nuts.

*BIV–2.4.1.1.2. Animal-derived food resources*

Food products obtained from livestock farming within the biosphere system. Type of product include:

- meat and offal (cow, sheep, pig, horse, goat, poultry)
- milk (cow, sheep, goat, horse)
- eggs
- fish.

*BIV–2.4.1.1.3. Fodder products*

Food products – especially pasture – cultivated or naturally available within the local biosphere that are intended for consumption by livestock.

*BIV–2.4.1.1.4. Natural food resources*

Food products obtained by gathering natural resources. Type of product include:

- fruit and nuts
- fungi
- fish
- game birds and animals.

*BIV–2.4.1.1.5. Non-food uses of biosphere products*

Resources obtained from the biosphere system that have non-food uses. Relevant products/uses include:

- construction (wood, soil, sediments, rocks, other plant materials)
- tools (wood)
- energy (wood, peat, waste products)
- furniture (wood, animal products, plant materials)
- clothing (animal and plant products)
- cosmetics (plant products, soils and sediments)

***BIV–2.4.1.1.6. Water***

| |
|---|
| Exploitation of biosphere water resources in domestic supplies – particularly as drinking water for humans and their livestock. |

*BIV–2.4.1.2. Storage of products*

| |
|---|
| Storage of biosphere products before use and/or consumption. |

*Storage of agricultural products, water and other materials prior to use/consumption may lead to changes in their radioactivity content and the stores themselves may contribute to additional pathways of exposure.*

*BIV–2.4.1.3. Location*

| |
|---|
| The time spent by an individual at different locations within the biosphere system. |

*Inhalation and external radiation exposure depends on the amount of time spent, and the shielding provided, at different locations within the biosphere system.*

*BIV–2.4.1.4. Diet*

| |
|---|
| Consumption rates of different food products. |

*The dietary habits of specific individuals can have an important influence on their levels of exposure.*

**BIV–2.4.2. External irradiation**

| |
|---|
| Exposures to contaminated sources resulting doses incurred via external irradiation. |

*BIV–2.4.2.1. External irradiation from the atmosphere*

| |
|---|
| Exposures to radioactive gases, vapours and aerosols present in the atmosphere. |

*BIV–2.4.2.2. External irradiation from soils*

| |
|---|
| Exposures to radioactive materials present in soils. |

*BIV–2.4.2.3. External irradiation from water*

| |
|---|
| Exposures to radioactive materials present in water – e.g. during fishing, bathing. |

*BIV–2.4.2.4. External irradiation from sediments*

| |
|---|
| Exposures to radioactive materials present in the sediments – e.g. during fishing or handling of fishing nets. |

*BIV–2.4.2.5. External irradiation from non-food products*

| |
|---|
| Exposures to radioactive materials present in building materials, furniture, clothing, cosmetics, medical applications etc. |

*BIV–2.4.2.6. External irradiation from the flora and fauna*

| |
|---|
| Exposures to radioactive materials present on plant surfaces or animal hides. |

**BIV–2.4.3. Internal exposure**

| |
|---|
| Intake of contaminated materials resulting in doses incurred via internal irradiation. |

*BIV–2.4.3.1. Inhalation*

| |
|---|
| Incorporation of radioactivity into the body in the form of aerosols, vapours or gases as a result of breathing. |

*BIV–2.4.3.2. Ingestion*

| |
|---|
| Incorporation of radioactivity into the body in water or other contaminated substances by ingestion. |

***BIV–2.4.3.2.1. Drinking***

| |
|---|
| Ingestion of drinking water, milk, water-based drinks, plant-derived drinks, water used in cooking. |

***BIV–2.4.3.2.2. Food***

| |
|---|
| Ingestion of foods derived from:<br>— plants<br>— fungi<br>— meat and offal<br>— dairy products<br>— fish<br>— eggs |

#### *BIV–2.4.3.2.3. Soil and sediments*

| |
|---|
| Ingestion of soil either inadvertently (e.g. with food products) or deliberately (pica). |

#### *BIV–2.4.3.3. Dermal absorption*

| |
|---|
| Incorporation of radioactivity into the body as a result of the absorption of contaminated substances through the skin. |

## REFERENCES TO ANNEX BIV

ELECTRIC POWER RESEARCH INSTITUTE, Biosphere Modelling and Dose Assessment for Yucca Mountain, EPRI Technical Report, TR-107190, December (1996).

SWEDISH RADIATION PROTECTION INSTITUTE, BIOMOVS II: Development of a Reference Biospheres Methodology for Radioactive Waste Disposal, BIOMOVS II Technical Report No. 6, Published on behalf of the BIOMOVS II Steering Committee by SSI, ISBN 91-972134-5-4, Stockholm (1996).

## ANNEX BV
## GENERIC DATA AND CORRELATIONS BETWEEN BIOSPHERE SYSTEM COMPONENTS AND CHARACTERISTICS

### BV–1. CLIMATE AND ATMOSPHERE

Temperature and precipitation parameters used in biosphere assessment models generally correspond to annual average values. Nevertheless, an understanding of the seasonal course of climate through the year can provide other relevant information about, for example, the hydrological conditions, such as annual evapotranspiration or likely summer soil moisture deficit. This type of information can be provided by the ecological climate diagram, which shows not only temperature and precipitation values but also the duration and intensity of relatively humid and arid seasons, the duration and severity of a cold winter, and the possibility of late or early frosts.

A typical climate diagram is shown in Figure BV–1, with accompanying text to explain the meaning of the co-ordinates, curves and annotations. The aridity or humidity of the different seasons can also be obtained from the diagrams by using the scale 10 ºC = 20 mm of precipitation. A potential evaporation curve thus takes the place of the temperature curve and, by comparing this with the precipitation curve, some idea of the water balance can be obtained.

Climate characteristics, such as those proposed in Table CII (Annex BI), can be based on information similar to that illustrated in Figure BV–1, which shows the sort of information that can be obtained for selected "analogue" stations.

Zonobiomes are mainly characterised (with some exceptions) by soil type and zonal vegetation. Broad descriptions of natural climax vegetational characteristics associated with different zonobiomes, correlated with typical soil types, are summarised in Table RT1.

TABLE RT1. ZONOBIOMES AND CORRESPONDING ZONAL SOIL TYPE AND ZONAL VEGETATION, WALTER (1984)

| Zonobiome | Zonal soil type | Zonal vegetation |
|---|---|---|
| ZB I | Equatorial brown clays (ferralitic soils, latosols) | Evergreen tropical rain forest |
| ZB II | Red clays or red earths (savanna soils) | Tropical deciduous forest or savannas |
| ZB III | Sierozems | Subtropical desert vegetation |
| ZB IV | Mediterranean brown earths | Sclerophyllous woody plants |
| ZB V | Yellow or red podzolic soils | Temperate evergreen forest |
| ZB VI | Forest brown earths and gray forest soils | Nemoral broadleaf-deciduous forest (bare in winter) |
| ZB VII | Chernozems to sierozems | Steppe to desert with cold winters |
| ZB VIII | Podzols (raw humus-bleached earths) | Boreal coniferous forest |
| ZB IX | Tundra humus soils with solifluction | Tundra vegetation (treeless) |

Defined for natural ecosystems and semi-natural systems that have not been substantially influenced by man.

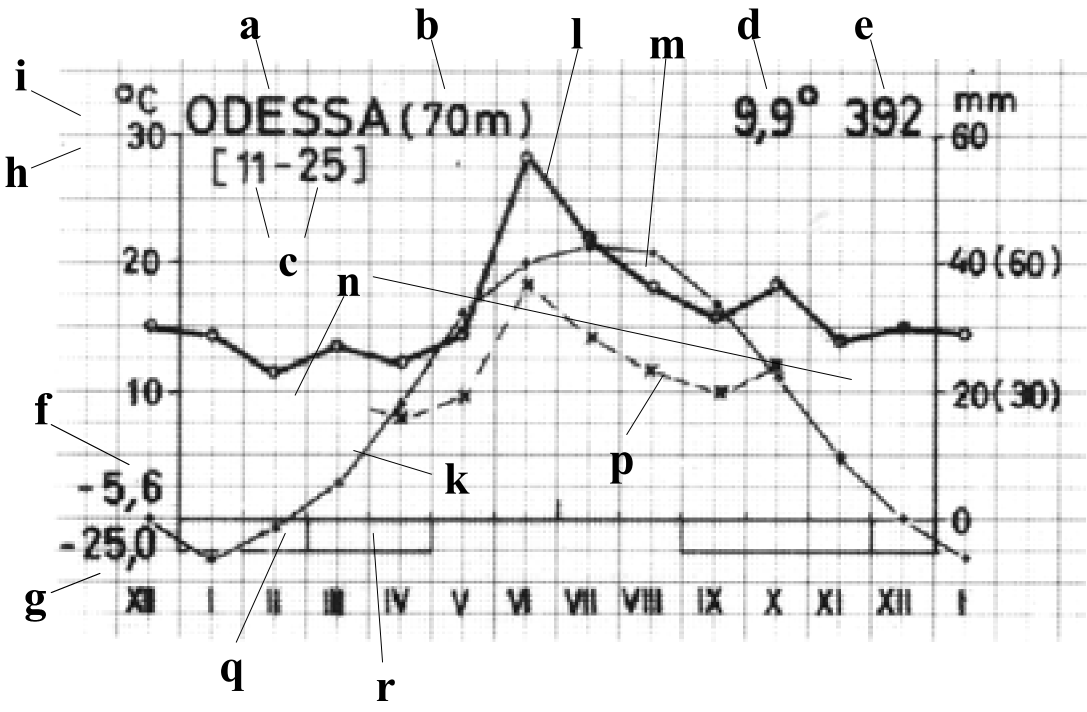



*FIG. BV–1. Construction of a climate diagram.*

Horizontal axis: months (January to December for Northern Hemisphere, July to June Southern H.). Vertical axis: left, mean monthly temperature; right, monthly precipitation of precipitation; for supplementary curve (see **(p)**). Temperature curve, thin line; precipitation curve, thick line; supplementary precipitation curve (only in steppe diagrams), broken line.

Text/numbers on the diagrams indicate: **(a)** station; **(b)** height above sea level; **(c)** number of years of observation (T, P); **(d)** mean annual temperature; **(e)** mean annual precipitation; **(f)** mean daily temperature minimum of the coldest month; **(g)** absolute minimum temperature; **(h)** mean daily temperature maximum of the warmest month (not given here); **(i)** absolute maximum temperature (not given here); **(k)** mean monthly temperature curve **(l)** curve of mean monthly precipitation; **(m)** period of relative drought; **(n)** corresponding relatively humid season; **(o)** mean monthly precipitation > 100 mm (perhumid season);**(p)** supplementary precipitation curve, area formed by p and k corresponds to the relative dry period (only for steppe stations); **(q)** months with a mean daily minimum below 0ºC, = cold season; **(r)** months with absolute minimum below 0ºC, with either late or early frosts. Representative examples of the nine zonobiomes can be found in Walter (1984) and The Climate Diagram World Atlas of Walter and Lieth (1967) contains diagrams for sites all over the world.

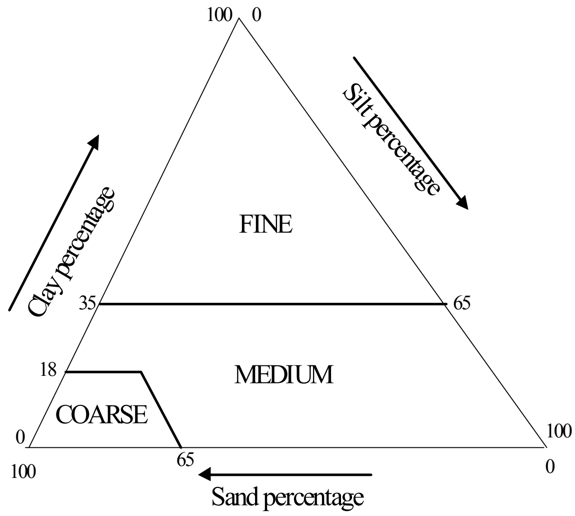
## BV–2. NEAR-SURFACE LITHOSTRATIGRAPHY

A summary is presented here of general information concerning the relationships between soil types and soil properties, and correlations between edaphology, geology and topography.

The soil quality factors most often used in reporting radioecological data are "soil texture" and "organic content" (as in IAEA (1994)). Texture refers to the relative proportion of clay, silt and sand in the soil and it characterises the soil according to particle size distribution. Horizon texture is one of the more permanent properties of soils, and allows other properties to be inferred directly according to the use or behaviour of the soil. Such properties might include hydrological characteristics, such as the soil moisture retention curve, as well as the degree of sorption of contaminants.

Textural class is given for the dominant soil in a given soil association and typically refers to the texture of the upper 30 cm of soil, which is generally the relevant depth for describing the behaviour of crop roots and water retention.

There are three main types of textural classes, derived from the USDA (1951) classification (see Figure BV–2). These are:




(1) **Coarse texture (sandy soils)**: sand and sandy-loam and loamy-sand with less than 18% clay and more than 65% sand.

(2) **Medium texture (loamy soils)**: sandy-loam, loam, sandy-clay-loam, loamy-silt, silt, loam-clay-silt and clay-silt with less than 35% clay and less than 65% sand. Sand percentage can be up to 82% if there is a minimum of 18% clay.

(3) **Fine texture (clay soils)**: clays, silt-clays, sandy-clays, loamy-clay and loamy-silt-clay with more than 35% clay.

*FIG. BV–2. Soil Textural Classification (USDA, 1951).*

The characteristics and qualities of soils as a function of the original parent material are discussed in Way (1973) and MMA (1996). For example, soils derived from sedimentary limestone rocks have particles mostly of fine silt and clays, with a structure that typically provides for excellent drainage and permeability. A textural classification of such soils, based on the USDA system, is shown in Figure BV–3.

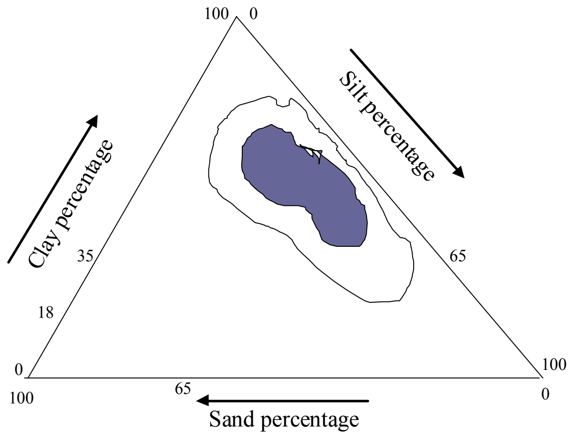



*FIG. BV–3. Textural classification for a limestone derived soil.*

"Soil density" and "porosity" are relevant modelling parameters related to soil texture and structure. Porosity and soil density are inversely related and regulate the movement of water in the soil and geological media.

Porosity in soils is usually expressed by means of the relation between the volume occupied by gases and liquids and the total soil volume. Porous size depends of the soil particle size and of the size of the aggregated particles. Hodgson (1985) establishes different porosity classes and density of aggregates as follows:

| | |
|---|---|
| **Porosity** *(% of the soil volume consisting of pores> 60 $\mu$m diameter)* | |
| Very low porosity | < 5.0 |
| Low porosity | 5.0 – 9.9 |
| Moderate porosity | 10.0 – 14.9 |
| Very porous | 15.0 – 20.0 |
| Extremely porous | > 20.0 |
| **Density of aggregates** | |
| Low | < 1.40 g cm-3 |
| Medium | 1.40 – 1.75 g cm-3 |
| High | > 1.75 g cm-3 |

Dunne and Leopold (1978) quote representative values for porosity (including both matrix and fracture porosity) in different consolidated and unconsolidated geological materials, as indicated in the following table:

| | | |
|---|---|---|
| **Porosity** *(%) as function of geological material* | | |
| *Consolidated rocks:* | | |
| Sedimentary rocks: | 5-30, except for "old crystalline limestone" (1-10) | |
| Metamorphic rocks: | 1-5 | |
| Igneous rocks: | Volcanic tuff: | 10-80 |
| | Lava | 1-30 |
| | Non altered granite | 1-5 |
| | Altered granite | 1-10 |
| *Unconsolidated rocks:* | | |
| Soils: | 30-50 | |
| Altered rock: | 1-50 | |
| Clays: | 45-55 | |
| Silt: | 40-50 | |
| Loess: | 40-55 | |
| Fine sand: | 30-40 (old sediments) | |
| Fine sand: | 45-52 (recent alluvial) | |
| Medium sand: | 30-40 (old sediments) | |
| Medium sand: | 35 (dunes) | |
| Coarse sand: | 30-35 | |
| Sand and gravel: | 20-30 | |
| Gravel: | 25-40 | |
| Glacial deposits: | 25-45 | |
| Dunes: | 35-40 | |

Millar et al., (1958) have established ranges of pH for different soils, based on providing indicators of the need for fertilising where such soils are used for agriculture, as follows:

<table>
<tr><td>pH</td><td colspan="10">4.0 5.0 5.5 6.0 6.5 6.7 7.0 8.0 9.0 10.0 11.0</td></tr>
<tr><td>Acidity</td><td colspan="2">Extreme acid</td><td>Very acid</td><td>Fairly acid</td><td>Slightly acid</td><td>Neutral</td><td>Slightly alkaline</td><td>Alkaline</td><td>Very alkaline</td><td>Excessively alkaline</td></tr>
<tr><td>Need for Lime</td><td colspan="2">Required except for acid soils crops</td><td colspan="2">Required except for crops that tolerate acid soils.</td><td>Not usually required</td><td colspan="5">Not required</td></tr>
<tr><td>Occur-rence</td><td>Rare</td><td>Fre-quent</td><td colspan="2">Very common in cultivated soils of humid climate</td><td colspan="4">Common in sub-humid and arid climates</td><td colspan="2">Limited areas in deserts</td></tr>
<tr><td>Soil group</td><td></td><td>Podzols</td><td colspan="2">Brown grey podzol soils.<br>Tundra soils</td><td colspan="2">Brown forest soils<br>Meadow soils<br>Latosols</td><td colspan="2">Chestnut and brown soils</td><td colspan="2">Black alkaline soils</td></tr>
<tr><td></td><td></td><td></td><td colspan="2"></td><td colspan="4">Tropical black earths</td><td colspan="2"></td></tr>
</table>

The expected effects of pH on trace element availability in soils has been established by the USDA (1971) as follows:

| pH | Expected effects |
|---|---|
| < 4.5 | Very unfavourable conditions |
| 4.5 – 5.0 | Probable toxicity by $Al^{3+}$ |
| 5.1 – 5.5 | Excess of: Co, Cu, Fe, Mn, Zn<br>Deficit of: Ca, K, N, Mg, Mo, P, S<br>Soils without calcium carbonate<br>Low bacterial activity |
| 5.6 – 6.0 | Adequate for most crop types |
| 6.1 – 6.5 | Maximum availability of nutrients |
| 6.6 – 7.3 | Minimum toxic effects<br>Soils with pH < 7.0 do not have calcium carbonate |
| 7.4 – 7.8 | In general soils with calcium carbonate |
| 7.9 – 8.4 | Decrease the availability of P and B<br>Increasing deficit of: Co, Cu, Fe, Mn, Zn<br>Ferric chloridation |
| 8.5 – 9.0 | In soils with calcium carbonate, this high pH can be due to $MgCO_3$ if there is insufficient exchangeable sodium present.<br>Greater problems with the ferric chloridation |
| 9.1 – 10.0 | Presence of sodium carbonate |
| > 10.0 | High percentage of exchangeable sodium<br>Toxicity: Na, B<br>Mobility of P as $Na_3PO_4$<br>Microbial activity very low |

For agrarian land, Marsh (1978) gives the following values for the run-off coefficient as a function of topography-vegetation and soil texture:

| Topography and Vegetation | Loam–sandy soils | Loam-silt and loam-clay soils | Clay soils |
|---|---|---|---|
| Forests: | | | |
| Plain zones (slope 0-5%) | 0.10 | 0.30 | 0.4 |
| Undulating zones (slope 5-10%) | 0.25 | 0.35 | 0.50 |
| Mountain zones (10-30%) | 0.30 | 0.50 | 0.60 |
| Meadows: | | | |
| Plain zones (slope 0-5%) | 0.10 | 0.30 | 0.40 |
| Undulating zones (slope 5-10%) | 0.16 | 0.36 | 0.55 |
| Mountain zones (10-30%) | 0.22 | 0.42 | 0.60 |
| Crops: | | | |
| Plain zones (slope 0-5%) | 0.30 | 0.50 | 0.60 |
| Undulating zones (slope 5-10%) | 0.40 | 0.60 | 0.70 |
| Mountain zones (10-30%) | 0.52 | 0.72 | 0.82 |

## BV–3. GEOLOGY/WATER BODIES

From the perspective of radiological impact assessment for solid waste disposal to land, subsurface water bodies and hydrogeological environments are of special interest owing to their role in transferring contamination to the surface by means of groundwater transport. The geology in this sense, including both the parent rock and the unconsolidated geology, has relevance as long as it is more or less able to support aquifers. The implications of the geology type for the properties of aquifers and aquicludes, especially those affecting the suitability as a water supply source, will be of importance in identifying and describing biosphere systems for long-term assessment. Geology is also an important consideration in terms of potential gas pathways to the biosphere, but the focus within BIOMASS is on the groundwater pathway.

Aquifers are found both in consolidated and unconsolidated geological formations. The extent to which they are used as sources of supply depends on local considerations. In some regions, consolidated formations (e.g. in sandstone and chalk) will tend to represent a more sustainable source of supply for long-term substantial abstraction. However, the majority of developed aquifers throughout the world are in fact in unconsolidated formations (Price, 1985).

Some typical aquifer types are described below (after (Maul et al., 1999)). The intention here is to provide illustrative examples of real situations, reflecting the type of information that might need to be obtained in a practical assessment involving consideration of aquifers.

### BV–3.1. ALLUVIAL AQUIFERS

The characteristics of a typical alluvial aquifer are shown in Figure BV–4. The unconfined unconsolidated aquifer lies in a river valley that changes in cross section along its course. Flow in the aquifer will generally be parallel to the river, but in some areas flow will be away from the river (recharge from the river) and in other areas this will be reversed with flow from the groundwater to the river (De Marsily, 1986).

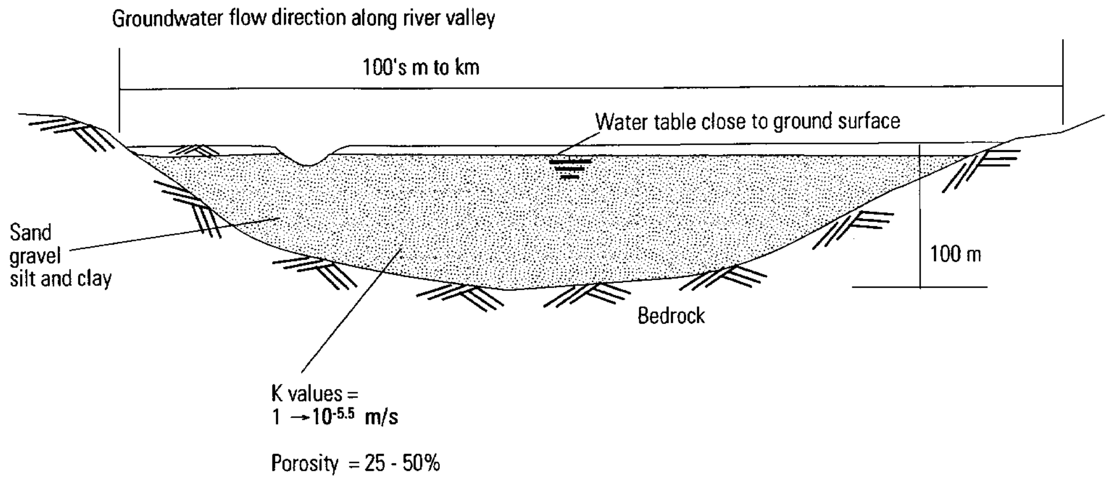



*FIG. BV–4. Alluvial aquifer (unconfined).*

BV–3.2. KARSTIC SYSTEMS

Karstic aquifer systems are formed in limestone due to dissolution processes. A typical karstic system is illustrated in Figure BV–5. Water that is saturated with a particular compound will not be able to dissolve any further material; hence dissolution occurs in the active near-surface region of the limestone units and most of the aquifer is unconfined.

Karstic aquifers are not an easy resource to exploit, as the siting of wells is often a matter of luck as to whether a large dissolution feature is encountered. When wells are successful, flows can be high but are also liable to dry up in any extended drought period. Karstic aquifers have generally very short delay times and tend to exhibit similar behaviours to that of river systems in that they will flood in times of heavy rainfall and dry up in droughts.

Flows in these aquifers are very concentrated and contamination that enters the system will be flushed through rapidly with little dilution or retardation. Due to the nature of limestone, surface water tends to be ephemeral in areas where karstic systems occur so that exploitation of the groundwater resource is often pursued despite the difficulties involved (Freeze and Cherry, 1979).

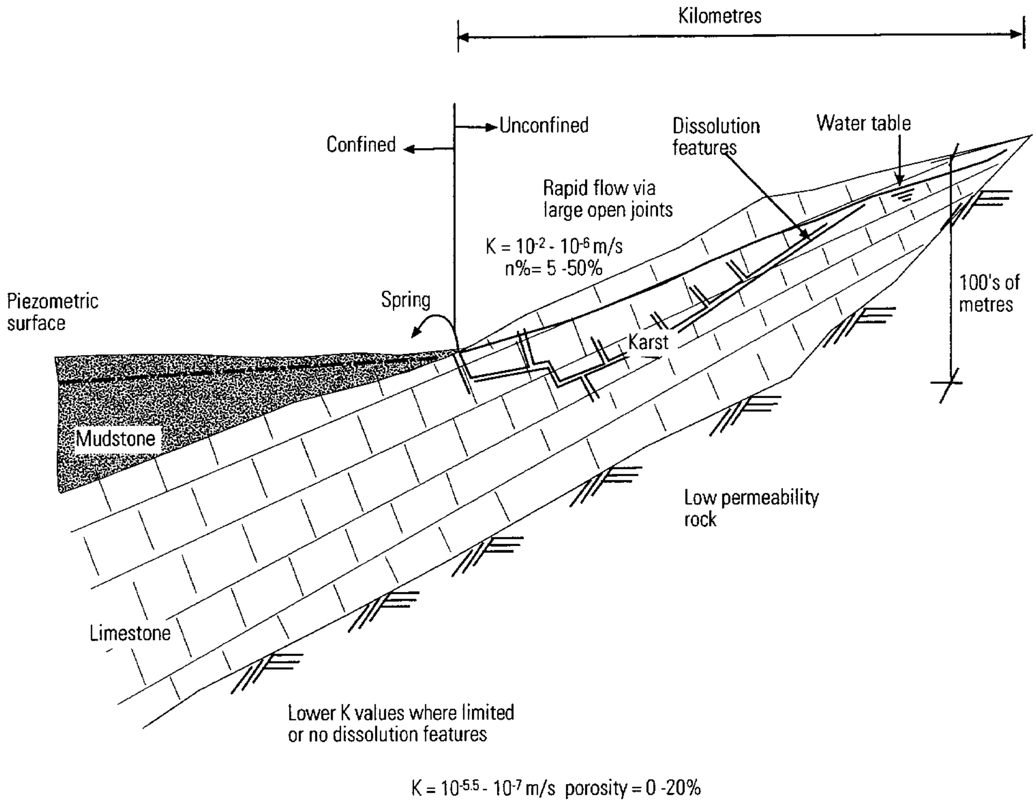



*FIG. BV–5. Kartsic aquifer system.*

## BV–3.3. VALLEY AQUIFERS

A typical valley aquifer system is illustrated in Figure BV–6. This type of unconfined aquifer system is developed when the near surface geology forms the aquifer. This is the case for chalk aquifers in southern England and northern France, where large expanses are available for recharge and the river systems act to drain the aquifers. The part of the aquifers where most useful amounts of water can be abstracted occur in the top few metres of the formation, and in the case of chalk, where secondary porosity is important, locations near to the river courses are more productive due to the larger throughput of groundwater in these areas.

For chalk aquifers the top 30 to 50 m is the most productive zone, as joints close up with depth and dissolution of carbonates does not occur so that the formation becomes almost impermeable (Price, 1985).

For sandstones the depth of typical aquifers can be two hundred metres. Often bedding planes play an important role in providing flow to wells, and it will tend to be the nearer-surface horizontal features that are more open due to unloading of the formation as a consequence of the removal of overlying deposits. Hence, even in sandstone aquifers the wells will tend to be shallow.

Similar geological environments in arid parts of the world will have similar geometrical properties, but the flow regime will be very different. In arid regions it is likely that recharge from local rainfall will be small; recharge to these aquifer systems often occurs from river flows of flood waters flowing in dry valleys (wadis) resulting from rainfall in mountains many miles away. Recharge to the aquifer occurs via the bed of the river and flow is away from the river valleys under the surrounding uplands (De Marsily, 1986).

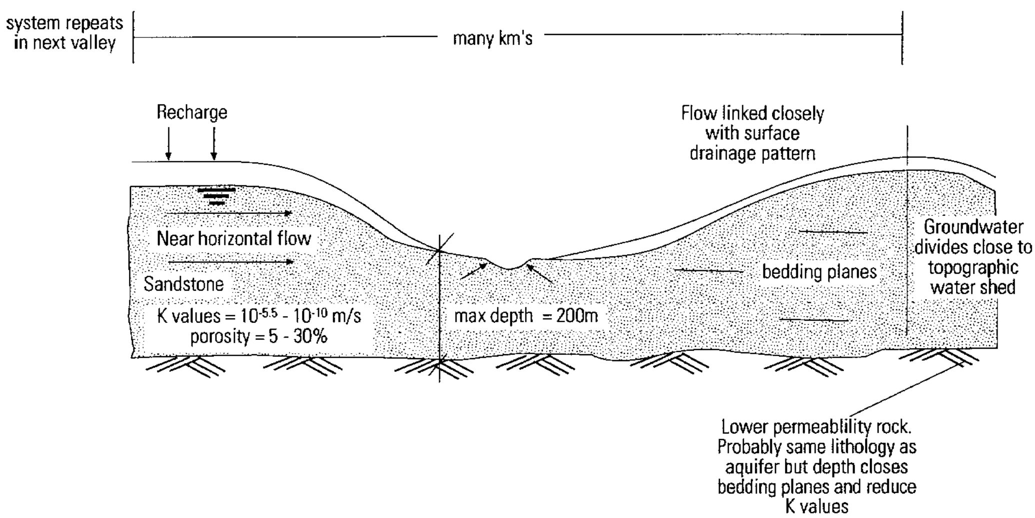



*FIG. BV–6. Valley aquifer.*

BV–3.4. GLACIAL DEPOSITS

Glacial deposits are often associated with low permeability clay material, but significant quantities of sands and gravels often can occur deposited as outwash material from glaciers. These deposits, although not generally large, can form important local aquifers.

In the UK, which has extensive glacial deposits, the interaction with the underlying unconfined aquifer system is often important in providing large volumes of water held in storage within the sands and gravels of the glacial deposits. This means that the base flows from the aquifers are often greater than would otherwise be the case (Freeze and Cherry, 1979).

BV–3.5. WEATHERED CRYSTALLINE ROCK

Crystalline rocks cover both igneous rocks and metamorphic rocks; for the purpose of this discussion the crystalline rocks are considered to have very low primary porosity (some igneous rocks can have high porosity). Thus, for the rock to develop sufficient porosity to hold water in useful quantities, secondary porosity is required.

The main processes by which this occurs are fracturing of the rock and weathering. The development of fractures due to faulting of the rock mass provides an increase in porosity and transmissivity of the formation; it also provides a means for the processes of weathering to locally penetrate deeper into the formation. The combination of these processes can produce regions in the rock mass that can be exploited as a water resource (Domenico and Schwartz, 1990); a typical situation is illustrated in Figure BV–7.

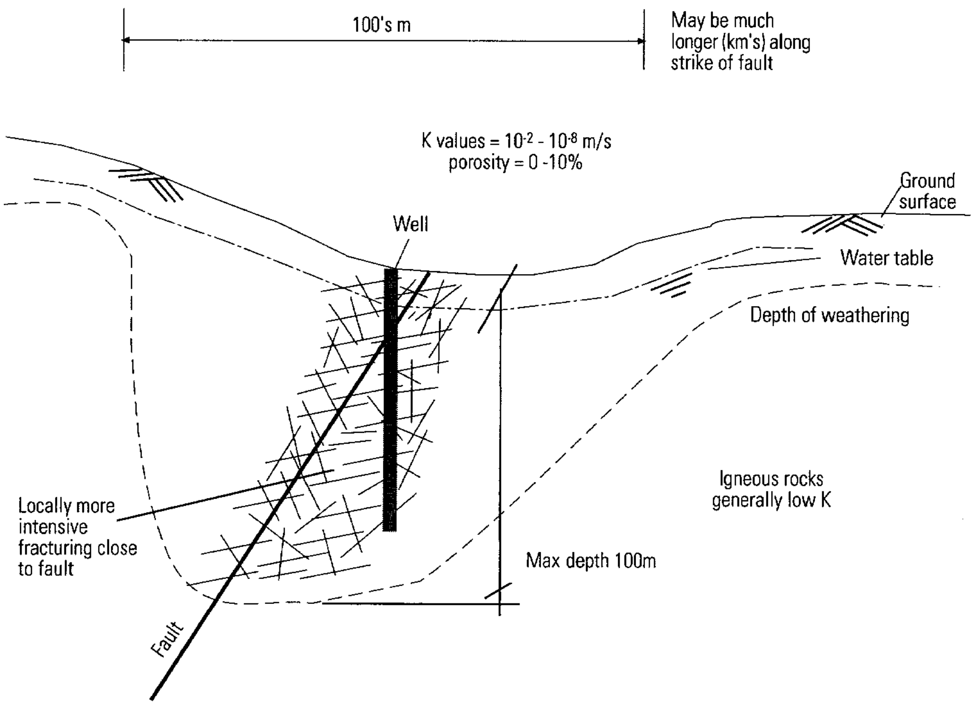



*FIG. BV–7. Weathered crystalline rock.*

## BV–3.6. SEDIMENTARY BASINS

Large sedimentary basin structures are common around the world and provide an ideal geometry for the development of confined aquifers. The most common lithologies associated with this type of aquifer are sandstones, which are sandwiched between layers of lower permeability formations. A typical system is illustrated in Figure BV–8.

These basin structures can be very large and provide important sources of water. However, they can often be very deep (several hundreds of metres) and require a high level of drilling technology to be able to exploit.

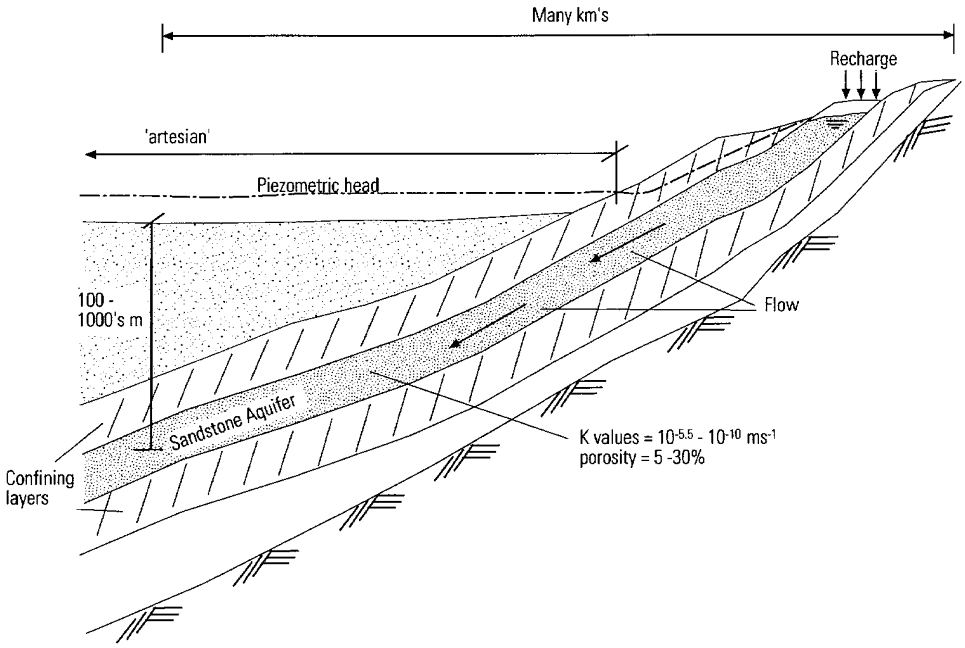



*FIG. BV–8. Confined sandstone basin aquifer.*

## BV–3.7. DIPPING STRATA

Dipping strata are another geometry of layered high and low hydraulic conductivity units. The recharge of the system up dip provides the input of fresh water into the system and overlying low permeability strata confine the aquifer.

These systems are similar to basin type structures, but are truncated in some way either by the presence of some low permeability material or, at coastal locations, the presence of a saline interface.

## BV–3.8. QUATERNARY DEPOSITS OF LOW HYDRAULIC CONDUCTIVITY

Quaternary deposits associated with the last glacial advance cover large areas of northern Europe and other parts of the world. Deposits are often made up of clay materials with very low hydraulic conductivities. Where these deposits overlay bedrock suitable as an aquifer they can effectively confine the underlying system.

The range of rock types that can form the aquifer below such deposits is large, as they can either be deposits that have good primary porosity to hold the water or can have previously been weathered to develop secondary porosity prior to being covered over.

**The hydrological cycle** in the biosphere relates to the exchange of water (in different states) between the hydrosphere, atmosphere, upper layers of the lithosphere and living organisms. This process can be described in terms of water balance equations for these individual biosphere components.

The water balance equation for the land surface (Budyko, 1986) expresses the condition that the algebraic sum of all forms of gain and loss of water in solid, liquid and gaseous states received at a horizontal surface at a specified time interval is equal to zero:

$$r - \left(E + f_w + G\right) = 0$$

where:

$r$ is the precipitation;
$E$ the evaporation;
$f_w$ the surface run-off; and
$G$ the flow of moisture to or from the land surface.

This equation is more often used in a slightly modified form, which can be derived by considering the fact that the vertical flow of moisture $G$ is equal to the sum of ground water flow $f_p$ and the change in the moisture content of the upper layers of the lithosphere $b$. This equality corresponds to the equation of water balance of a vertical column that extends through the upper layers of the lithosphere down to the depths where, for practical purposes, it can be assumed that no moisture exchange takes place.

The sum of surface run-off $f_w$ and ground water flow $f_p$ is equal to the total discharge within the catchment $f$, such that:

$$r = E + f + b$$

This equation can also be used in the calculation of water balance of water bodies or their individual sectors. In this case, $f$ describes the total horizontal redistribution of water over the period under consideration within the water body itself and underlying layers of the ground. Also, $b$ corresponds to the total change in water content within the water body and underlying ground layers. Often, therefore, $b$ will correspond to changes in water level.

The various components of water balance for surface and subsurface water bodies can be seen in the following table:

| Term | Ground | Water bodies |
|---|---|---|
| *r* | Precipitation, irrigation | Precipitation |
| *E* | Evaporation<br>Transpiration | Evaporation |
| *f* | Infiltration<br>Runoff (Sheet flow, Gully flow)<br>Ground water discharge, spring discharge<br>Porous medium/Fracture flow<br>'Macropore flow' | Surface Water Flows<br>• River and stream flow<br>• Flow in lakes and reservoirs<br>• Wetland flows<br>• Estuarine flows (Freshwater, Tidal, Residual)<br>• Marine flows (Tidal, Residual)<br>• Flow of Ice<br>• Ground water recharge flow<br>Subsurface Water Flows<br>• Porous medium/Fracture flow<br>• Ground water discharge flow<br>• Changes in water bodies level (e.g. seasonal changes) |
| *b* | Interception<br>Leaf drip<br>Stemflow<br>Throughflow<br>Interflow | |

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# PART C

## EXAMPLE REFERENCE BIOSPHERES

## C1. INTRODUCTION

The purpose of this document is to provide practical examples that demonstrate how biosphere models for long-term assessment can be developed and justified as being fit for purpose. The intention is to explore the extent to which a limited set of representative Reference Biospheres, systematically defined according to the BIOMASS Methodology in Part B, might usefully be seen as 'international standard measuring instruments' of the potential radiological impact of radionuclide releases that may occur in the far future. The assessment contexts for the examples have been designed to be as widely relevant as possible.

Example 1 is most simple, involving no biosphere evolution, a simple geosphere-biosphere interface (GBI) and only consideration of annual individual effective doses[11] from consumption of well water. Example 2 involves consideration of other types of GBI and calculation of doses to members of hypothetical exposure groups arising from a wide of exposure pathways within agricultural and semi-natural environments, but without allowing for evolution of the corresponding biosphere system. Example 3 requires the consideration of biosphere change, at specific and generic sites.

## C2. EXAMPLE REFERENCE BIOSPHERE 1, DRINKING WATER WELL

Example Reference Biosphere 1 (ERB1) is deliberately designed to be very simple, being focused on a simple biosphere system and single exposure pathway. It is characterised by a drinking water well bored through the overburden into an aquifer that has been contaminated by radionuclide releases from the repository. Previous experience from more comprehensive biosphere modelling studies has shown that a drinking water well may sometimes represent a significant or even, depending on other aspects of the assessment context, a dominant pathway for release and exposure.

The Example has been explored in two variants. In the first (ERB1A), it is assumed that a geosphere model for the site of interest is able to support the calculation of radionuclide concentrations in well water. In the second (ERB1B), it is assumed that the biosphere model domain includes the near surface aquifer from which the well water is drawn. This will illustrate the importance of assumptions embodied in the total system performance assessment relating to the geosphere/biosphere interface and their implications for the development of biosphere system descriptions and models.

It is recognised that different levels of detail and/or different types of complexity will often be employed as part of a comprehensive performance assessment. The assumption of an uncomplicated biosphere – such as a well used for drinking water – might therefore be relevant as one element of the 'multiple lines of reasoning' used to build confidence in the overall assessment. As such, the Example described here could assist in the identification of key differentiating factors in total system performance, such as the design and/or representation of engineered barriers, or the geological host formation. This might, in turn, assist with providing proof of concept, in guiding research priorities, or as part of site screening programme.

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[11] 'Annual individual effective dose' is reduced to 'dose', unless otherwise indicated.

The simplicity of ERB1 serves clearly to identify where key questions lie in relation to the GBI. Being simple, the Example also illustrates the BIOMASS Methodology and the importance of clearly identifying the basis on which biosphere modelling assumptions are made.

## C2.1. ASSESSMENT CONTEXT FOR EXAMPLE REFERENCE BIOSPHERE 1A (ERB1A)

The assumed assessment context is summarised as:

| | |
|---|---|
| Assessment Endpoint: | Annual individual effective dose. |
| Assessment Philosophy: | 'Cautious' |
| Repository Type: | Deep repository for long-lived solid radioactive waste. |
| Site Context: | Temperate climate, inland repository, aquifer at accessible depth, no biosphere change. |
| Geosphere/Biosphere Interface: | Well intruding into aquifer plume with abstraction limited to a rate consistent with domestic use. Concentrations of radionuclides in the abstracted water (including relevant short-lived daughters) are assumed to be provided by geosphere transport models, and are maintained indefinitely at a constant unit concentration for each radionuclide. |
| Source Term: | Wide range of radionuclides. |
| Societal Assumptions: | Present-day use of domestic water consistent with Temperate environment. The only exposure pathway to be assessed is drinking water, obtained from the well, assuming no monitoring or water treatment. |
| Time Frame: | Up to 1 million years. |

Each of these components of the context is now considered further.

### C2.1.1. Assessment purpose

The general purpose of a biosphere model in radioactive waste disposal assessment is to provide a mechanism for estimating the radiological significance of potential future discharges of radionuclides. In the present case, a very simple reference biosphere is desired, which can still be considered a useful guide to repository performance. There are potential multiple purposes for a biosphere indicator of this type, which may include one or more of the following:

Purpose: Guide Research Priorities (Geosphere, Near Field and Engineered System).
Proof of Concept.
Regulator/Scientific Confidence.
Guide to Site Selection.

One incentive for using a simple approach is therefore assumed to be the identification of key differentiating factors in total system performance, such as the design and/or representation of engineered barriers, or the geological host formation. Such a role for the biosphere model could assist with providing proof of concept, in the identification of geosphere research priorities, or as a guide to site selection. A simplified approach has also been suggested as being of value in applications where the main emphasis is to compare the relative performance of different engineered and natural barriers.

Furthermore, it is recognised that different levels of detail and/or different types of complexity will often be employed as part of a comprehensive performance assessment. The assumption of a relatively simple biosphere – such as a well used for drinking water – might therefore be relevant as one element of the 'multiple lines of reasoning' used to build confidence in the overall assessment.

All four 'purposes' identified above are therefore considered as being potentially relevant to this Example. It is important that the results of the exercise are reviewed in order to evaluate the model's applicability to these different assessment purposes, along with the extent to which the results satisfy other components of the assumed assessment context.

### C2.1.2. Assessment endpoints

Different radionuclides are associated with distinct radiological hazards per unit activity. Guidance in respect to research priorities and site selection will not therefore necessarily be provided on the basis of release rates (from the repository or geosphere) alone. There is a need to describe the potential behaviour of radionuclides and potential radiation exposures in sufficient detail to reflect the varying levels of radiological harm they could cause.

Most radiation protection standards incorporate limits on individual effective dose and, for simplicity, consideration is restricted here to the evaluation of annual individual effective dose. However, the limited nature of ERB1A is such that the results are best considered simply as 'conversion factors' between release rate and dose rate, rather than somehow as calculations of the 'true' dose.

No age group (for the exposed individual) is specified, although it is recognised that specific requirements could possibly be imposed via regulatory guidance. Detailed specification of the exposed individual is addressed under 'Exposure Group Definition', Section C2.4.

### C2.1.3. Assessment philosophy

The assessment philosophy provides a broad indication of how it is presumed that irreducible uncertainties should be addressed through basic assessment assumptions. Hence a cautious philosophy will tend to result in the use of generally conservative assumptions in order to ensure that, within the overall constraints imposed on the assessment, the results are unlikely underestimate the corresponding dose that would arise for the release and exposure mechanisms considered. For example, whereas a contaminated well may be just one of several possible sources of drinking water available to people at some time in the future, a cautious assessment approach dictates that exposures should be calculated only for those individuals for whom the well is assumed to be the sole source.

Nevertheless, adoption of a 'cautious' assessment philosophy within a particular assessment context will not guarantee that the assessment provides an upper bound estimate of the maximum potential exposure. Thus, in the case of ERB1A, the adoption of drinking water as the only pathway of exposure is not necessarily cautious. In particular, if well water were also to be used for irrigation of crops, accumulation processes in soil and plant material might give rise to exposures (for certain radionuclides) substantially greater than those for drinking water alone. Exploration of other Example Reference Biospheres will help to determine the extent to which potential exposures could be underestimated as a result of this basic assumption.

#### C2.1.4. Repository type

Details of the repository type are largely unimportant to this Example. The main reason for identifying a deep geological repository for ERB1A was the generally high degree of interest in this mode of waste disposal among BIOMASS Theme 1 participants.

#### C2.1.5. Site context

Details of the site context are not particularly relevant to model development for this Example, although they may have some bearing on its ultimate applicability. For example, as a matter of practicality, the assumed location of any well should be such that the contaminated aquifer is at a reasonably accessible depth, based on the presumed habits and technology of the inhabitants of the local region. Thus it would perhaps be unreasonable to assume that a well for drinking water supply is drilled to a depth of 400 m at a mountain-side location if such drilling is inconsistent with present-day practice. Likewise, this Example will be less relevant to locations where the geography or climate make the use of wells to provide potable water unlikely. As a rule, information concerning the assumed location of the well would tend to be verifiable for any specific application.

The limited extent of the biosphere system of interest (restricted to water delivered at the well-head and its subsequent use in domestic supply) means that the assumption of Temperate climate should not have a major influence on model development, except in so far as climate affects the presumed water consumption rate. Again, however, verifiable information would normally be available in respect of the particular climate characteristics relevant to any specific application of the Reference Biosphere. The presumption of no biosphere change, although strictly unrealistic, is intended to ensure that the Example remains meaningful but uncomplicated.

#### C2.1.6. Geosphere/biosphere interface

In ERB1A, it is assumed that geosphere modelling supplies all necessary information regarding the concentrations of radionuclides in water delivered at the well head. Hence, all flow and transport effects, together with any dilution arising as a result of pumping and other changes within the well itself, are assumed to be provided externally to the biosphere model. Clearly, it is necessary for the geosphere and biosphere modelling activities to be co-ordinated in order to ensure that assumptions related to pumping volumes and aquifer capacity in the geosphere model are consistent with the societal assumptions (e.g. community demand and water treatment) within the biosphere model.

#### C2.1.7. Source term

In order to enhance the potential applicability of the results, the source term is assumed to incorporate a wide range of radionuclides (and their respective progeny) which previous assessments have suggested could be present in groundwater releases (Vieno and Nordman, 1999). The concentration of each radionuclide in well water is assumed to be constant; hence the results of the biosphere calculations will provide ‘conversion factors’ for annual individual effective dose per unit concentration in water at the well head. Radioactive progeny with relatively short half-lives will be assumed to be in secular equilibrium with their abstracted water. The specific radionuclides considered are tabulated with data and results in Section C2.8.

The assumption that radionuclide concentrations in well water are maintained constant indefinitely is recognised to be unrealistic, implying that the source of radionuclides is effectively unlimited. It should be borne in mind, however, that the purpose of ERB1A is simply to provide a meaningful indicator of potential radiological impact conditional upon an assumed release to the biosphere. The assumption of an 'indefinite' release is simply intended to ensure that restrictions are not applied unnecessarily to possible applications of the Example.

#### C2.1.8. Societal assumptions

To avoid endless speculation regarding the technology, physiology and socio-economic structures of future communities, the primary assumption is made that the activities and characteristics of the population exploiting the well water are similar to those of present-day communities. This is believed to be consistent with the IAEA's general principle of ensuring that predicted impacts on the health of future generations will not be greater that the relevant levels of impact that are acceptable today (IAEA, 1995).

The artificial restriction of considering exposure only via the drinking water pathway is adopted for two reasons: (1) to maintain simplicity and (2) to establish a baseline reference case that is of broad general interest and potential applicability.

The assumption of no monitoring or water treatment is intended to ensure that no credit is taken for systems that might detect (and thereby mitigate the impact of) radionuclides present in the water supply. This is consistent with the assessment philosophy outlined previously; indeed, the specific requirement to exclude monitoring and water treatment could be considered redundant given the overall need to adopt a 'cautious' approach.

#### C2.1.9. Time frame

The intention is that the Example should be relevant to potential releases that might occur within such a time frame; it is not intended to imply that the biosphere should be assumed to remain constant for a period of one million years.

### C2.2. BIOSPHERE SYSTEM IDENTIFICATION AND JUSTIFICATION FOR ERB1A

For this Example, the biosphere system is not precisely defined by legislation or guidance and so the relevant components of the biosphere system have to be identified and justified. However, many elements of the assessment context are quite prescriptive – much of the identification and justification of the biosphere system and its components (including the fact that biosphere change is ignored) can be derived directly from the requirements of the assessment context. The Example cannot therefore be regarded as an exacting test of the BIOMASS Methodology in this respect; nevertheless, it is considered important to apply the approach as rigorously as is practicable.

No directions are given in respect of application to a particular site. If a specific site had been identified it could be expected that some judgments would appear somewhat less arbitrary (for example, in describing the local topography – see below). However, application to a specific site might also be expected to add to the complexity of other decisions (for example, in relation to human activities).

The approach requires the identification of the biosphere components and selection of component type from a list of Tables identified in the BIOMASS Methodology (see Type I Tables in Annex BI of Part B). Primary components are those without which the system definition would be considered incomplete. Information applicable to secondary components can potentially be derived from that defined for the primary components (e.g. in order to provide a consistent overall description of the biosphere system); however, in many cases, such information may simply not be required for the particular assessment context under consideration.

The following components of the biosphere system are indicated for ERB1A. In all cases, the justification is derived directly from the assessment context:

- *Human activities:* Primary – domestic use of water drawn from the well. The nature of the community is considered a primary component because human activities are directly responsible for the route and extent of biosphere contamination, through the exploitation of the aquifer as a water resource. The assumed withdrawal rate must be consistent with domestic usage by the community exploiting the water resource.
- *Climate:* Primary – Temperate, present day. The characteristics of climate are considered a primary component in so far as they can influence the volume of water that is used (and, in particular, consumed) by the local community, as well as possible requirements for temporary storage.
- *Topography:* Secondary – detailed consideration of topography is not a significant element of the biosphere system description. Indeed, the surface relief and arrangement of biosphere features could even be classed as irrelevant owing to the assessment context, which requires consideration only of dose via human consumption of drinking water abstracted from a well. One possible issue of interest might be the configuration of water distribution and storage systems used by the local community; however, these may perhaps be more properly considered under human activities. The actual topography of the land surface needs only to be consistent with the primary assumption of well abstraction.
- *Location:* Secondary – not a significant component of the biosphere system description. The assessment context requires only that consideration be given to exposures incurred via the direct consumption of drinking water drawn from a well under present day Temperate environmental conditions. However, the location of the well (as represented in the geosphere calculations) needs to be consistent with the primary requirement that water is available in sufficient quantities and at an accessible depth.
- *Geographical extent:* Primary – limited to the well head from which the contaminated water is assumed to be taken, together with the distribution system for domestic use. Geographical extent is therefore important in so far as the physical domain of interest is explicitly constrained by the requirements of the assessment context.
- *Biota:* Secondary – does not need to be considered as an important component of the biosphere system. The assessment context excludes consideration of flora and fauna.
- *Near-surface lithostratigraphy:* Secondary – not significant as an explicit part of the biosphere system owing to the assessment context, which restricts consideration to well water only. Concentrations of radionuclides in abstracted water are assumed to remain constant at levels determined by geosphere transport models. The actual lithostratigraphy needs only to be consistent with the assumption that water from the

aquifer is available at accessible depth and that it requires no treatment before use (i.e. hydrogeochemistry falls within potable standards).

— *Water bodies:* Secondary – do not need to be included, as it is not part of the system description as defined by the assessment context. However, certain properties of the aquifer (such as the presence of trace elements – e.g. stable iodine – which could have an impact on the turnover of radioactive isotopes in the human body) may be relevant to the dose assessment.

The assessment context specifies that biosphere system change need not be considered. A constant biosphere system based on present-day conditions can therefore be assumed. No further steps are required in implementation of the approach for identifying and justifying biosphere systems.

## C2.3. BIOSPHERE SYSTEM DESCRIPTION FOR ERB1A

A more detailed description is now made of the component types and characteristics (See Type II Tables of Annex BI of Part B) of the biosphere system relevant to the assumed assessment context. The review process takes into account the list of 'primary' components identified above.

### C2.3.1. Anthropology/sociology

#### *C2.3.1.1. Population and community description*

A precise description of the local population structure (e.g. the size of the community, its use of local resources, etc.) is considered to be largely irrelevant to the biosphere system description, which (according to the assessment context) is intended to be generically applicable. However, it is relevant to note that, in practice, site-specific factors can be a major determining factor on local community structures. For example, in certain situations (e.g. high volume flow in the aquifer, combined with suitable terrain) it is possible that abstraction could be intended to serve a large population. In other situations, site-specific circumstances (remote location, difficult terrain, etc.) may dictate that only a small community (perhaps a small farm or temporary camp) is likely to be present.

It can be inferred from the assessment context that technological development is sufficient to allow for abstraction of water to take place. The actual level of technology required would depend on the specific situation in which abstraction takes place. Simple excavation into a shallow aquifer requires less technology than pumping from a borehole drilled into a deep, relatively impermeable, formation.

Although not strictly part of the system description for this Example, consideration of local community structures may be implicit in other basic assumptions adopted regarding the biosphere system and/or exposure groups. For example, a small, remote (or even temporary) community may be less likely to invoke complex water storage and distribution systems prior to use, whereas industrialised abstraction for a larger population might involve more sophisticated technologies.

Although consideration of population size does not necessarily influence the biosphere system description, it may be important in applying and interpreting the results. For example, the size should be consistent with the underlying geosphere characteristics, in so far as radionuclide concentrations in well water are assumed to be unaffected by withdrawal rates, or variations in withdrawal rates. It might also be inferred from the assessment context that, if water abstraction is to be sustainable over an indefinite period, population size should be compatible with the capacity of the aquifer. Moreover, the overall community context (combined with local lithostratigraphy) may affect the type of well that is constructed, and hence the potential (as well as the realised) abstraction rates in any given situation. Predication of a particular abstraction rate (necessary to guide the geosphere calculations) will constrain the type of well that can be used.

*C2.3.1.2. Human habits*

Human activities that are relevant to providing a description of the biosphere system are those which relate to the influence of human action on the biosphere. For this example, these are already explicitly addressed under 'Land Use' and 'Use of Water Resources', below. The detailed description of human habits is therefore considered irrelevant to the biosphere system description. It is nevertheless recognised that consideration of habits (i.e. what individual people do and how much time they spend doing it) is relevant to the characterisation of potential exposure groups, particularly in terms of defining their water consumption.

*C2.3.1.3. Human diet*

Aspects of diet that are pertinent to the description of the biosphere (total consumption, fraction derived locally) are considered to be adequately addressed under 'Land Use' and 'Use of Water Resources', below. Broader considerations of 'Human Diet' are therefore considered irrelevant to the biosphere system description.

For the present Example, total water utilisation by the community depending on the well could be considered relevant because this will determine the overall abstraction rate from the aquifer. However, the assessment context indicates that concentrations in well water are time-invariant and can be determined by geosphere transport models only (i.e. they are not influenced by the assumed abstraction rate). This issue is discussed further under 'Use of Water Resources' below.

Whereas a detailed description of human diet is not important to the biosphere system description here, the fact that water is a part of human diet is clearly directly relevant to the overall assessment. The existence of a potable water supply therefore needs to be recognised in the system description. Moreover, the presence of trace elements in the diet might be important in determining the turnover of radioactive isotopes in the human body and may therefore be relevant to the exposure assessment. For example, consideration of such issues could (in principle) contribute to the selection of data to support the calculation of ingestion doses.

*C2.3.1.4. Land use*

A description of local land use is not relevant to this particular Example, because the geographical extent of the biosphere system is explicitly constrained to the well head and the use of contaminated well water for domestic purposes only.

#### *C2.3.1.5. Use of water resources*

This characteristic of human behaviour is fundamental to the overall assessment context and is therefore highly relevant to the biosphere system description. It is noted that the assessment context restricts consideration to the use of well water for domestic supply only, thereby excluding agriculture and horticulture (e.g. irrigation), recreation (e.g. supply for swimming pools) and industry. Given that 'time-invariant' concentrations in well water are assumed to be supplied by geosphere models, the total volume of water used by the community is not directly relevant to the biosphere system description. Nevertheless, in determining such concentrations, an understanding of the total abstraction rate (sufficient to support the domestic requirements of the assumed community), combined with consideration of hydrogeological conditions, would be needed to ensure coherence across the overall performance assessment. Consideration therefore needs to be given to abstraction rate at some stage, even if it is not directly relevant to the determination of dose 'conversion factors' based on unit concentrations in water at the well head.

No guidance is provided in the assessment context with respect to the disposal of wastewater (or sewage sludge). This could potentially be an important consideration for some radionuclides, for example if wastewater (or sewage sludge) were used to support gardening or agriculture (not a totally unreasonable expectation). However, this possibility is considered in ERB2. Hence, it is assumed for the purposes of ERB1A that wastewater simply 'disappears' from the domain of the biosphere system. Although deliberate water treatment prior to consumption is explicitly excluded by the assessment context, certain passive processes (e.g. sorption, sedimentation) occurring during distribution and storage could potentially be relevant for some radionuclides.

#### *C2.3.1.6. Physiological characteristics*

A detailed description of human physiological characteristics is not relevant to the biosphere system description, although it clearly needs to be considered in the characterisation of exposure groups.

Those aspects of human physiology that are pertinent to the biosphere system description are the factors influencing dietary intake and hence the overall exploitation of local resources by the local community. However, as already noted, total water consumption by the local community is largely irrelevant to the biosphere system description in this assessment context, because concentrations in well water are assumed to be time-invariant and are not influenced by the assumed abstraction rate. Moreover, considerations related to the water abstraction rate are already addressed under consideration of the 'Use of Water Resources' (see above). Likewise, where appropriate, the characterisation of other types of resource exploitation would be addressed under 'Land Use'. It is therefore concluded that consideration of 'Physiological Characteristics' is irrelevant to the biosphere system description for this Example.

### C2.3.2. Climatology

#### *C2.3.2.1. Climate characteristics*

Consideration of climate characteristics contributes to providing a coherent overall description of the biosphere system, in so far as they determine:

- precipitation as an input to the availability and quality of local surface water resources (and hence demands on aquifer use);
- temperature, insolation and wind speed as potential influences on evaporative losses during storage of domestic water;
- temperature and other factors as an influence on the water requirements of the local community.

The cautious approach dictated by the assessment context requires that the aquifer should be assumed the only source of drinking water for the exposed group, and that radionuclide concentrations in well water are not influenced by the assumed abstraction rate. It is not therefore considered that the detailed characterisation of climate will have a significant influence on the biosphere model. Nevertheless, climate factors (defined as part of the system description) will be relevant in determining individual consumption rates for exposed individuals (and hence total radiological exposure). 'Temperate' climate is specified within the assessment context.

*C2.3.2.2. Temporal variability of climate*

The assumed assessment context for ERB1A specifies no biosphere change, and requires that water consumption should be consistent with a Temperate environment. Nevertheless, shorter-term variability may be relevant to the radiological assessment, in so far as the demand for water (and the need for storage facilities) could be influenced by climate fluctuations over interannual or decadal timescales. Nevertheless, it is not considered that detailed characterisation of temporal variability will be important to the selection of a biosphere model (for the same reasons as outlined under 'Climate Characteristics' above).

*C2.3.2.3. Spatial variability of climate*

The assessment context specifies that the geographical extent of the region of interest is limited to the well from which the water is withdrawn. Hence, there is highly unlikely to be any significant spatial variability in climate over the domain of the biosphere system, and this factor can be considered irrelevant to the system description. On the other hand, application to a particular site (at a given latitude, distance from the coast, altitude and aspect) might be expected to make any specific specification of climate characteristics, for a given application of the model, seem less arbitrary.

*C2.3.2.4. Factors determining climate*

The assessment context specifies no biosphere change, requiring water consumption to be consistent with a Temperate environment. Therefore there is no need to consider factors that determine climate as part of the biosphere system description, except in so far as they may contribute to uncertainty in parameter values relevant to Temperate conditions. Factors determining climate are therefore considered irrelevant.

### C2.3.3. Ecology

The assessment context restricts consideration to the use of well water for domestic supply only, thereby excluding agriculture (e.g. irrigation), recreation (e.g. supply for municipal swimming pools) and industry. Disposal of wastewater (or sewage sludge) could potentially be an important consideration for some radionuclides, for example if it were used to support gardening or agriculture. However, although this possibility is noted, it is excluded from further consideration according to the underlying context. Hence, descriptions of ecosystems and the plant, animal and microbial communities they support are considered irrelevant to the biosphere system description.

*C2.3.3.1. Geology/geomorphology/edaphology*

The assessment context restricts consideration to the use of well water for domestic purposes, with time-invariant concentrations of radionuclides in well water assumed to be determined solely by geosphere models. Local land use is not relevant and the assessment context specifies no biosphere change. Hence, soils and geological features, including factors influencing landform change, are considered irrelevant to the biosphere system description.

*C2.3.3.2. Hydrology/hydrogeology/glaciology/geochemistry*

*Water bodies*

The assessment context restricts consideration to the domestic use of well water abstracted from a subsurface water body, with time-invariant concentrations of radionuclides in water at the well head being determined solely by geosphere transport models. Hence, there is no need to consider attributes related to saturated, or variably saturated, zones as part of the biosphere system description. All water bodies (except the domestic water supply system) therefore lie outside the domain of the biosphere system of interest and are irrelevant to the system description.

*Water body characteristics*

The assessment context precludes consideration of factors such as the geometry of, and flow rate within, the aquifer, which lies outside the domain of the biosphere system. Descriptions of water inputs and outputs, surface water flows, sea level and freeze/thaw phenomena are also not required in order to characterise the system within the bounds established by the assumed context.

However, although the subsurface water body from which water is assumed to be extracted lies outside the domain of the biosphere system, certain features of the water itself may be relevant to the system description. For example, suspended sediments present in water abstracted from the aquifer could be affected by processes during storage, thereby influencing the radiological impact of certain radionuclides. The chemical composition of the well water could also influence the potability of the supply or the presence of trace elements, which may have an impact on radiological exposures. Nevertheless, because the assessment context dictates a 'cautious' assessment approach, it seems likely that the physical and chemical properties of the abstracted water should ultimately be described in such a way as to de-emphasise their possible effect on radiological impact.

### C2.3.4. Summary of biosphere system description for ERB1A

The attributes deemed to be 'relevant' or 'potentially relevant' to a comprehensive description of the biosphere system relevant to ERB1A are therefore identified as follows:

— water as a part of human diet;

— abstraction of water for domestic purposes via a well intruding into a sub-surface aquifer;

— water distribution and storage prior to domestic use;

— characteristics of a temperate climate;

— temporal variability of temperate climate on interannual or decadal timescales;

— physical (e.g. suspended sediment load) and chemical (e.g. potability, trace element content) composition of abstracted well water.

This list is generally consistent with the primary components identified earlier (identification and justification of biosphere systems). Most of the relevant and potentially relevant features fall under the general headings of Human activities and Climate. However, the Water Bodies component (incorporating the physical and chemical composition of well water) was not previously identified as being of primary importance.

One approach to representing dependencies between each of the biosphere system attributes identified above is to use a form of influence diagram (BIOMOVS II, 1996a). The preliminary system adopted here is to develop a comprehensive representation of these relationships using an 'Interaction Matrix' approach (see Figure C1). Using this approach, each of the leading diagonal elements (LDEs) of the matrix represents a relevant attribute of the biosphere system (as summarised above), while the off-diagonal elements (ODEs) are used to identify potential influences and interactions.

## C2.4. EXPOSURE GROUP DEFINITION FOR ERB1A

### C2.4.1. General description of the hypothetical exposure group(s)

The description here should be sufficient to form the basis for defining particular patterns of behaviour and should be consistent with underlying assumptions regarding wider community structures and the relationship of such communities to their environment. The level of detail required will depend on the specific approach taken in performing the calculation.

For ERB1A, the only exposure group of interest is that consisting of those individuals who obtain all their drinking water requirements from the well. No limit is placed on the size of the group as far as the biosphere calculation is concerned; however, potential constraints on overall population size (and hence the demand on the well) need to be considered in establishing the corresponding geosphere modelling calculations. The adoption of a cautious assessment approach dictates that exposures should be calculated only for those individuals for whom the well is assumed to be the sole source of drinking water.

A cautious approach dictates that exposure rates should account for the total volume of water that is consumed, including any used in water-based drinks. Water entering the local distribution system at the well head is assumed to be untreated. However, the action of making drinks (e.g. boiling the water to make tea or coffee) may further modify characteristics of the water, beyond any passive changes that occur during storage and distribution.

| | | | | | |
|---|---|---|---|---|---|
| Temporal variability of climate characteristics | Affects the climate in any single year | No | No | Variability may influence requirements for storage | No |
| No | Characteristics of a Temperate climate | Affect the volume of water required by the community | Not directly – water characteristics are assumed invariant | May be minor influences such as losses during storage | Not directly – drinking water supply is needed whatever the climate |
| No | No | Abstraction of water for domestic use | No – abstraction does not affect characteristics (defined by context) | Can't store or distribute water until it has been abstracted | Drinking water supply comes from abstraction (defined by context) |
| No | No | It is only worth abstracting the water if its composition is suitable | Physical and chemical characteristics of well water | No | Water must be potable to be used in drinking supply |
| No | No | No | No | Water storage and distribution prior to domestic use | May affect quality of water supply |
| No | No | If water is consumed, it must be abstracted first | No | No | Water as a part of human diet |

*FIG. C1. Interaction Matrix representation of associations and influences between relevant attributes of the biosphere system for ERB1A.*

## C2.5. MODEL DEVELOPMENT FOR ERB1A

### C2.5.1. Conceptualisation of biosphere system description

In moving from a summary description of the overall biosphere system to its conceptualisation, the first requirement is to distinguish between different types of attributes. This involves a review of the relevant system components and interactions summarised in Figure C1, aimed at separating those FEPs that relate to interactions between physical features within the temporal and spatial domain of interest from those that can be considered as 'external influences' on the biosphere system. In practice, the following 'modelling' steps can therefore be distinguished:

(a) Identification of factors that can be considered as being outside the domain of the system of interest (i.e. the external elements) – essentially, this determines those parts of the overall system that will be assumed to act as external data drivers. Thus, a modelling decision is made to decouple the representation of the biosphere system domain relevant to radiological assessment from any modelling that may be required to determine the externally-supplied data.

(b) Differentiation of the internal components of the system to separate: (a) the physical features of the biosphere; (b) characteristics of those physical features; and (c) events and processes that operate within, or between, the different physical features, affecting their characteristics.

(c) Representation of the biosphere system in the domain of interest for radiological assessment in a revised, more concise, form of Interaction Matrix. Within such a matrix, the LDEs correspond to distinct physical features of the system (objects) possessing particular characteristics (attributes). Events and processes may be considered as operating entirely within individual physical features of the system (LDEs), or as actions that transform the characteristics at one physical location to those at another (ODEs).

For the biosphere system relevant to this Example Reference Biosphere, the external factors were identified as:

— climate characteristics (temperate); and

— temporal variability of climate characteristics.

Hence, such factors (including, for example, temperature and wind speed) are retained as issues to be addressed in modelling, but only in as much as they may influence model parameter values such as the consumption rate of drinking water.

Relevant physical features of the biosphere system are:

— water supply delivered at the well head; and

— water supply delivered to consumers.

These features have been differentiated in order to allow for potential changes to the physical and chemical characteristics of the water supply that may occur during distribution and storage. For the purposes of the present Example, therefore, facilities used in water storage and distribution are represented by taking account of how they may affect the composition of the water. The resulting Interaction Matrix is shown in Figure C2.

| | | | |
|---|---|---|---|
| **Radionuclide Source** | Contamination from geosphere | | |
| | Water at Well Head | Storage and distribution | |
| | | **Water Supplied for Drinking** | Drinking |
| | | | Exposure Group |

*FIG. C2. Summary representation of the radionuclide transport and exposure pathways relevant to radiological assessment modelling for ERB1A.*

At this stage, the ODEs of the matrix related to relevant radionuclide transport and exposure processes are described in summary form only. The next step in the process of developing the conceptual model is therefore to amplify these descriptions to include all possibly relevant Features, Events and Processes. This is achieved by screening a comprehensive, independent FEP-list, taking into account the overall assessment context (see Annex BIV of Part B). A complete record of the screening process for this Example, summarising the various screening arguments, is provided in Table C1. The results of the screening exercise are summarised in a revised version of the Interaction Matrix, as shown in Figure C3.

### C2.5.2. Conceptual model development

A conceptual model for the purposes of radiological assessment is now developed from the 'complete' Interaction Matrix shown in Figure C3. The first step in this process is to identify whether or not screening arguments can be developed for discarding FEPs shown in the matrix, for example by making approximating assumptions (taking into account the required 'cautious' nature of the assessment).

| | | | |
|---|---|---|---|
| **Radionuclide Source** | Contamination from geosphere | | |
| | Water at Well Head | Microbial metabolism, evaporation/ degassing, sedimentation and remobilisation, chemical change, adsorption/ desorption, dredging of sediment. | |
| | | **Water Supplied for Drinking** | Water consumption (including suspended sediment), preparation of water-based drinks |
| | | | Exposure Group |

*FIG. C3. Interaction Matrix representation of the radionuclide transport and exposure pathways for ERB 1A, including results of the FEP screening process.*

TABLE C1. RECORD OF FEP SCREENING FOR ERB1A

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 1 | Assessment context | Y | Assessment Context issues are addressed in Section C3.1 of the Report |
| 2 | Biosphere system features | Y | See discussion below |
| 2.1 | Climate | Y | Included, but as external influence |
| 2.1.1 | Description of climate change | N | Precluded by Assessment Context |
| 2.1.2 | Climate categorisation | Y | Characteristics of Temperate climate and their temporal variability considered as possible influences on biosphere system |
| 2.2 | Human Society | Y | Addressed in so far as the exploitation and distribution of water resources is fundamental to the system definition |
| 2.3 | Systems of exchange | Y | May be relevant at local scale – e.g. microbial communities within water distribution system |
| 2.3.1 | Environment types | N | Biosphere system extent is confined to the domestic water distribution system, starting at the well head |
| 2.3.2 | Ecosystems | Y | Potential interest in microbial communities as a characteristic of water in supply system: (2,2) and (3,3) |
| 2.3.2.1 | Living components of ecosystems | Y | Microbial communities in water supply – considered as part of the water system |
| 2.3.2.2 | Non-living components of ecosystems | Y | Water supply, distribution and storage system used by the community: (2,2) and (3,3) |
| 3 | Biosphere events and processes | Y | See discussion below |
| 3.1 | Natural events and processes | Y | See discussion below |
| 3.1.1 | Environmental change | N | Precluded by assessment context |
| 3.1.2 | Environmental dynamics | Y | Implicitly included in choice of parameters via influence of external climate drivers |
| 3.1.2.1 | Diurnal variability | N | Not relevant to annual average water use and/or consumption |
| 3.1.2.2 | Seasonal variability | N | Not relevant to annual average water use and/or consumption |
| 3.1.2.3 | Interannual and longer timescale variability | Y | May influence consumption of water in any given year – also potential impact on requirements for water storage |

TABLE C1. RECORD OF FEP SCREENING FOR ERB1A (CONTINUED)

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 3.1.3 | Cycling and distribution of materials in living components | Y | Microbial metabolism may affect characteristics of water (2,3) |
| 3.1.4 | Cycling and distribution of materials in non-living components | Y | See discussion below |
| 3.1.4.1 | Atmospheric transport | Y | Possibility of evaporation and/or degassing during storage/distribution (2,3) |
| 3.1.4.2 | Water-borne transport | N | Details of water transport in the storage and distribution system (flow rate, etc.) not relevant to assessment context |
| 3.1.4.3 | Solid-phase transport | Y | Some processes may serve to change characteristics of the water supply (2,3) – see discussion below |
| 3.1.4.3.1 | Landslides and rock falls | N | Not relevant |
| 3.1.4.3.2 | Sedimentation | Y | Settling of suspended sediments in the water distribution/storage system |
| 3.1.4.3.3 | Sediment suspension | Y | Remobilisation of sediment during periodic maintenance of supply system |
| 3.1.4.3.3 | Rain splash | N | Not relevant |
| 3.1.4.4 | Physicochemical changes | Y | Some processes may serve to change characteristics of the water supply (2,3) – see discussion below |
| 3.1.4.4.1 | Dissolution/precipitation | Y | Possibility of passive chemical transformation in water supply system |
| 3.1.4.4.2 | Adsorption/desorption | Y | Potentially relevant to r/n concentration if there are changes in sediment load |
| 3.1.4.4.3 | Colloid formation | N | Does not affect the determination of r/n concentration in bulk water |
| 3.2 | Events and processes related to human activity | Y | Relevant in so far as system of water abstraction/storage/distribution is defined by human activity |
| 3.2.1 | Chemical changes | N | Not relevant |
| 3.2.2 | Physical changes | Y | The ‘biosphere system’ of interest is man-made – but assessment context excludes consideration of impacts on groundwater |
| 3.2.3 | Recycling and mixing of bulk materials | Y | Relevant in that water supply system is man-made – periodic cleaning/dredging? (2,3) |
| 3.2.4 | Redistribution of trace materials | Y | No deliberate processing of water supply, but passive changes may occur (e.g. in preparation of drinks) (3,4) |

TABLE C1. RECORD OF FEP SCREENING FOR ERB1A (CONTINUED)

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 4 | Human exposure Features, Events and Process | Y | See discussion below |
| 4.1 | Human habits | Y | See discussion below |
| 4.1.1 | Resource usage | Y | Exploitation of water resources implicit in system description; other resources excluded by assessment context |
| 4.1.2 | Storage of products | Y | Water may be stored in distribution system prior to consumption |
| 4.1.3 | Location | N | Not relevant |
| 4.1.4 | Diet | Y | Stable element components of diet may be relevant in determining exposures for some radionuclides |
| 4.2 | External irradiation | N | Excluded by assessment context |
| 4.3 | Internal exposure | Y | See discussion below |
| 4.3.1 | Inhalation | N | Excluded by assessment context |
| 4.3.2 | Ingestion | Y | Consumption of contaminated water (including suspended sediment) as supplied, or in water-based drinks etc. |
| 4.3.3 | Dermal absorption | N | Excluded by assessment context |

Although suspended sediment may be present in the water supply, the total sediment load must be low enough for the water to remain potable, as deliberate water treatment is assumed not to take place. Sedimentation may occur over time, but it will generally be cautious to exclude its effects, and to assume that the total concentration of radionuclides in the bulk water volume is not changed as it passes through the supply system. Periodic dredging of the tank, involving disturbance of accumulated sediment, could give rise to a 'spike' in concentration resulting from the desorption of radionuclides. This would potentially be important if the focus of interest were the dose from water consumption in a specific year; over a longer period, however, the annual average concentration in the water supply should not exceed that delivered at the well head.

Degassing within the storage and distribution system might bring about the loss of some volatile radionuclides; it will therefore be generally cautious to exclude such a process. By contrast, evaporation of water during storage and distribution could give rise to an increase in the concentration of those radionuclides that remain in solution. In principle, a simple supporting calculation should be employed to assess the potential importance of evaporation to the overall assessment endpoint. However, it can be anticipated that the water loss and corresponding increase in concentration associated with this process are unlikely to be significant in the context of a typical water supply system used in a Temperate environment.

Microbial activity could potentially change the chemical form of radionuclides and stable elements present in the water supply. The assessment context (which excludes water treatment) dictates that any such changes will not be significant enough to affect the potability of the supply. Moreover, as a general rule, the chemical composition of radionuclides will depend on various factors (including sorption to suspended sediment) many of which are unlikely to be known. If information cannot be provided as part of the source term it will generally be appropriate to assume that radionuclides are consumed in a chemical form that leads to the highest gut uptake factor and hence dose per unit activity ingested.

Preparation of water-based drinks might also lead to changes in the chemical form of radionuclides and stable elements. Again, however, it will be appropriate to assume that radionuclides are consumed in the chemical form that leads to the highest dose per unit activity ingested. Evaporation from water that is boiled to make hot drinks could give rise to increased radionuclide concentrations in solution; however, the effects of this on the total intake of activity are reckoned minor by comparison with overall uncertainties in total water consumption.

The decay and ingrowth of radionuclides during transport through the water distribution and storage system could potentially affect the equilibrium concentrations of certain short-lived radioactive progeny. Given that the model is intended to be generically applicable, it will not be appropriate to include explicit representation of transport through the distribution system. However, it will be cautious to assume that short-lived progeny (i.e. those with half-lives comparable with, or less than, the mean time spent by water in the distribution network) are present in the drinking water supply in equilibrium with their parents, whatever the original concentrations may have been at the well head.

In summary, therefore, some of the processes identified in Figure C3 might increase the concentration of radionuclides in the drinking water supply, some might decrease the concentration, while the effect of others is not clear. Taken together, however, it is reckoned that the combined impact of such processes on calculated concentrations in water, and the corresponding radiation dose, will not be very significant, particularly given the assumed range of purposes for assessments in which the model is likely to be used. For example, a factor of (say) from 2 to 4 uncertainty in the overall result arising from such considerations is unlikely to be important in assessments used to guide research priorities in the geosphere or to assist with proof of concept or site selection. As a general rule, therefore, it should be possible to ‘proceed with caution’, recognising that such uncertainties exist when the results are eventually applied.

It would generally be useful to obtain as much relevant information as possible in relation to the source term at the geosphere/biosphere interface, apart from the concentration of radionuclides. For example, it is particularly important to know whether the concentration is expressed in terms of the bulk water volume (i.e. including suspended sediment) or if it relates only to the amount in solution. Given the discussion above, bulk concentrations are considered more relevant to the biosphere modelling and assessment approach adopted for ERB1A. Other potentially relevant information would include chemical properties of the water and suspended sediment load, especially if the overall results were to be used to guide site selection or geosphere research priorities.

In the light of the above, it should be possible to delete from the conceptual model all processes represented in the Interaction Matrix as being associated with the water storage and distribution network, or with the preparation of drinks. No biosphere dynamics, or radionuclide transport and accumulation within the biosphere system, are therefore addressed within the model. Calculated effective doses will then be directly proportional to the specified concentration of radionuclides in the water supply.

### C2.5.3. Mathematical model development

In the light of the above discussion, it is possible directly to write down the mathematical model as a proportional relationship between annual individual effective dose and the bulk concentration of radionuclides in water delivered at the well head. Thus:

$$H_{E,i} = C_{w,i} * I * dcf_i$$

where:

$H_{E,i}$ annual individual dose from radionuclide i (Sv $y^{-1}$);
$C_{w,i}$ bulk concentration of radionuclide i in water delivered at well head (Bq $m^{-3}$);
$I$ consumption rate of drinking water ($m^3$ $y^{-1}$); and
$dcf_i$ ingestion dose coefficient for radionuclide i (Sv $Bq^{-1}$).

In choosing values for the different parameters used in the mathematical model, various issues identified during the course of the biosphere system description and model development process are relevant. These include the following:

— It is assumed that the activity concentration in water delivered at the well head (as specified by the geosphere models providing the source term for the calculation) is expressed as a bulk quantity (i.e. including both dissolved and suspended sediment phases).
— Radionuclides with half-lives comparable with, or shorter than, the mean time spent by water in the distribution network should be assumed to be present in secular equilibrium with their parents.
— Consumption rate of drinking water corresponds to the total including water-based drinks. The amount may be age-dependent, and climate considerations may be important in determining values for this parameter.
— Dose coefficients should (cautiously, given uncertainties regarding chemical form and changes in the distribution and storage network) correspond to the highest reasonable gut uptake factor for each radionuclide. It is recognised that metabolism may be affected by the presence of trace elements in the diet, and is also likely to be correlated with age and other physiological characteristics, including total water consumption. Nevertheless, care needs to be taken if a decision is taken to move away from recognised metabolic models.

### C2.5.4. Selection of data

The data protocol developed as part of the BIOMASS Methodology involves following a series of steps for each parameter required by the model (see Annex BII of Part B). These steps can be summarised as:

(a) *Introduction*: Identification of the relevant elements of the assessment context and data requirements, coupled with a summary of available information corresponding to the parameter(s) of interest.

(b) *Structuring*: The data evaluation problem is then structured to provide an unambiguous definition of the parameter(s) of interest, identifying relevant factors and assumptions that drive data determination. Possible correlations with other parameters used in the model are also identified.

(c) *Conditioning*: The nature of the required estimate (pdf, upper bound, central value, etc.) is defined. If required, the procedures used to derive, or condition, available data sources are described. Qualitative implications associated with data bias, correlations and/or extreme outcomes are discussed.

(d) *Encoding*: Values for the quantity of interest are derived and relevant caveats made explicit.

(e) *Output*: A record of sources of information, decisions made and assumptions adopted in deriving the data values is produced.

It is not made explicit in the assessment context whether the endpoint of the calculation (annual individual effective dose) is intended to represent the maximum potential individual dose in a single year, or the average annual dose over a longer period. Indeed, it would seem that either of these interpretations should be suitable to the type of assessment purpose the biosphere calculation is expected to support. However, some of the FEP screening arguments adopted above are founded on the assumption that the calculation corresponds to the average annual dose from ingestion of contaminated water throughout an individual's adult life.

#### *C2.5.4.1. Ingestion dose coefficient*

The ingestion dose coefficient, $dcf_i$ (Sv Bq$^{-1}$), is a measure of the radiological impact associated with the ingestion of a given radionuclide, and is to be specified here for a range of different radionuclides. Available reference information includes relevant ICRP documentation and international safety standards.

In the context of safety assessment for radioactive waste disposal, the ingestion dose coefficient falls into the category of parameters that are assigned definitive values according to data provided by authoritative national and/or international sources. For ERB1A, the ingestion dose coefficient for each radionuclide is to be characterised as a single-valued parameter (i.e. without uncertainty), defined according to internationally-approved values for adults. The IAEA Safety Series document on basic safety standards presents tabulated values for the ingestion dose coefficient varying with the age of the exposed individual (Table II-VI of (IAEA, 1996)).

It is understood that, in the compilation of the values presented in the basic safety standards document, the highest of the identified possible values for element-dependent gut uptake was cautiously selected in determining the ingestion dose coefficient for each radionuclide. IAEA advises that variation of the dose coefficient with age should be taken into account in dose assessments for individuals other than adults; however, no other sources of uncertainty or variability are indicated in the reference material. The data used in the biosphere model for this Example are therefore read directly from the final column (corresponding to adult members of the public (>17 years)) of Table II-VI (IAEA, 1996).

*C2.5.4.2. Consumption rate of drinking water*

The drinking water consumption rate, $I$ ($m^3$ $y^{-1}$), is to be determined for adults, with consideration given to variation with age. The water consumption rate adopted for the purposes of the dose calculation is therefore assumed to be the 95%ile value from the distribution of consumption rates for young adults. Both national (e.g. (WRC, 1980)) and international (CEC, 1991; 1995) information sources are available.

The consumption rate of drinking water is the amount of water ingested by an individual in a year. In the context of safety assessment for radioactive waste disposal, the parameter is typically expressed as an annual average value. Data values for individuals (particularly children and infants) are poorly characterised, and will normally depend on a range of internal and external factors, such as metabolic rate and climate.

According to a European Commission report (CEC, 1991) water consumption rates for individuals recommended by the 'Article 31 Expert Group' are given as 600 kg $y^{-1}$ for adults, 300 kg $y^{-1}$ for children (10 years) and 250 kg $y^{-1}$ for infants (1 year). Other published recommendations by the European Commission (CEC, 1995) are based on values given by the IRCP (ICRP, 1975), indicating individual consumption rates of 0.6 $m^3$ $y^{-1}$ for adults, 0.35 $m^3$ $y^{-1}$ for children and 0.26 $m^3$ $y^{-1}$ for infants. These latter values are explicitly stated to exclude intakes of water in food (including milk), by oxidation of food, by inhalation or by absorption through the skin.

Table C2 summarises data for daily consumption of drinking water in Great Britain (WRC, 1980).

ICRP Publication 23 (ICRP, 1975) gives total fluid intakes by ingestion for adults and children as 3 litres per day and 2 litres per day, respectively. The reference adult value, although greater than other published fluid intake rates, is based on consideration of total water balance and the physiological premise that 1 ml of water is required for each kcal of energy expended. Neglecting any water ingested in food and milk, and produced by the oxidation of food, ICRP Publication 23 suggests water intake rates of 1.65 litres per day for adults and 0.95 litres per day for a ten-year-old child. These values are 0.55 and 0.475 of the total fluid intake rates derived from the physiological relationship that 1 ml of water is required for each kcal of energy expended. This suggests that some intake above metabolic requirements occurs, at least in the middle and upper parts of the distribution.

Taking the British survey for total fluid consumption by males aged 18-30 years, but reducing the values by 10% to allow for milk consumption (NRPB, 1996) and then scaling by a further factor of 0.84 to allow for the lower energy consumption of adult females (approximately 0.68 that of adult males) gives the following values appropriate to a mixed sex, young adult population (see Table C3). The 95%ile value for reference young adults (1.2 $m^3$ $y^{-1}$) is approximately a factor of two greater than the mean adult consumption rate recommended by ICRP (1975). The value of 1.2 $m^3y^{-1}$ is adopted for ERB1A calculations.

TABLE C2. SURVEY DATA FOR DAILY CONSUMPTION OF DRINKING WATER IN A TEMPERATE CLIMATE

| | Tap water and all drinks made from tap water (litres per day) All ages | Males, 31-54 years | Total liquids (litres per day) Males, 18-30 years |
|---|---|---|---|
| Mean | 0.96 | 1.09 | 2.18 |
| $90^{th}$ | 1.57 | 1.68 | 3.49 |
| $95^{th}$ | 1.9 | $2.16^{+}$ | $4.31^{+}$ |
| $97.5^{th}$ | 2.2 | $2.2^{+}$ | $5.00^{+}$ |
| $99^{th}$ | 2.60 | $2.95^{+}$ | $5.9^{+}$ |

**Notes:**

- males consume more than females at all ages;
- highest consumption of tap water based drinks, for both sexes, is at ages 31-54;
- highest consumption of total liquids (including alcoholic beverages, bought soft drinks and, possibly, milk) is at age 18-30 for males, 31-54 for females;
- certain data values ($^{+}$) have been derived from (WRC, 1980), assuming that the higher percentiles scale in the same way to the mean as for "all ages".

TABLE C3. DERIVED DAILY CONSUMPTION OF DRINKING WATER BY REFERENCE YOUNG ADULTS

| | Total Liquid Consumption of Males 18-30 Years (l $d^{-1}$) | Total Water Consumption of a Reference Young Adult (l $d^{-1}$) | Total Water Consumption of a Reference Young Adult ($m^3$ $y^{-1}$) |
|---|---|---|---|
| Mean | 2.18 | 1.66 | 0.61 |
| $90^{th}$ | 3.49 | 2.65 | 0.97 |
| $95^{th}$ | 4.31 | 3.28 | 1.2 |

#### *C2.5.4.3. Commentary on assumed data values*

The variability of the ingestion dose coefficient with age is generally less than one order of magnitude (IAEA, 1996). Moreover, water consumption rates are typically smaller for children and infants (by factors of 2 to 3) than for adults. In addition, the duration of infancy and childhood is short compared with a potential lifetime of chronic exposure. Differences between adults, infants and children in the radionuclide-dependent ingestion dose (Sv per Bq $m^{-3}$) associated with the consumption of contaminated drinking water are therefore reckoned to be generally well within an order of magnitude, particularly if these are considered on the basis of lifetime annual average values. Such small variance is believed unlikely to be significant in the assumed generic assessment context, which is focused on supporting decisions related to site screening/selection, research priorities, or proof of concept.

## C2.6. EXAMPLE REFERENCE BIOSPHERE 1B (ERB1B)

Example Reference Biosphere 1B has been developed as a further relatively simple test of the BIOMASS Methodology, also with the general objective of developing a simple, yet meaningful, biosphere assessment model. It is similar to Example 1A, being based on the assumed use of abstracted groundwater in drinking water supply; however, the geosphere/biosphere interface is relocated to the 'place of discharge' to the aquifer, rather than the well head. This is intended to illustrate the significance of geosphere/biosphere interface assumptions, reflecting the fact that, in many performance assessments, geosphere models typically specify the boundary condition as a flux to the biosphere, rather than a concentration.

### C2.6.1. Assessment context for ERB1B

This is as for ERB1A, except for a different GBI, which for ERB1B is:

| | |
|---|---|
| Geosphere/ Biosphere Interface: | Geosphere discharge into aquifer. Radionuclide release rates (including short-lived daughters) into the aquifer from the deeper geosphere are assumed to be provided by geosphere transport models. The release rates of radionuclides into the aquifer are assumed to be maintained indefinitely at constant values for each radionuclide. |

It is assumed that geosphere modelling supplies a calculated release rate of radionuclides into an aquifer system from which water may be abstracted. The fact that rates of dilution need to be calculated in order to determine concentrations relevant to radiological assessment tends to diminish the potential generic applicability of this Example. Local considerations, such as the area over which the geosphere model determines that a release will occur and volumetric flow rates in the aquifer, will be relevant in any use of such a model to guide site selection or to support safety case development. Nevertheless, the implication of the assessment context, is that a general system description should somehow be developed to represent this type of interface, and that specific problems regarding model development and implementation should be addressed.

### C2.6.2. Biosphere system identification and justification for ERB1B

The following additions and differences in the biosphere system are indicated for ERB1B compared with 1A. In all cases, the justification is derived directly from the assessment context:

— *Human activities:* It is important to recognise that pumping from an aquifer may alter the natural equilibrium of water fluxes within the biosphere. In order to be consistent with a long-term assessment that assumes no biosphere change, the flow field – including the effects of abstraction – must be time-invariant in the long-term, although short-term fluctuations could be integrated into the definition of the biosphere system. Sustainability considerations will also place a ceiling to the amount of perturbation on the aquifer caused by human actions. The flow field is then considered to have reached a long-term equilibrium.

— *Climate:* Primary – Temperate, present day. Climate characteristics are considered a primary component in so far as evapotranspiration and precipitation will influence the recharge of (and natural discharge from) the aquifer, and temperature (for example) may affect the water requirements of the local community. Short-term fluctuations in annual climate may influence requirements for the development of temporary storage facilities.

— *Topography:* Secondary – detailed consideration of topography is not a significant element of the biosphere system. The assessment context indicates that the primary consideration is the flow field in the aquifer; hence, factors affecting this flow field are not fundamental to the system description, although they may be relevant to a detailed understanding of the system. Indeed, for a specific site, characterisation of this flow field would be the important concern, whether or not this was determined by consideration of topographic (and lithostratigraphic) considerations.

— *Location:* Secondary – not a significant component of the biosphere system for a generic assessment context. The assessment context requires only that consideration be given to exposures incurred via the direct consumption of drinking water abstracted from the aquifer under present day Temperate environmental conditions. However, in any of practical use of the assessment model corresponding to the assumed biosphere system, the location of the well needs to be consistent with the availability of water in sufficient quantities at an accessible depth.

- *Geographical extent:* Primary – limited to the region of the aquifer and the well from which the contaminated water is assumed to be abstracted, together with any distribution system for water used by the community. Geographical extent is therefore important in so far as the physical domain of interest is constrained by the requirements of the assessment context. The assessment context also requires that the aquifer should be at 'accessible depth'.
- *Biota:* Secondary – not a significant component of the biosphere system relevant to the assessment context. It is nevertheless recognised that flora and fauna (particularly deep-rooted trees) may have an important impact on the sub-surface flow field; although not fundamental to the required biosphere system description, they may be relevant to a detailed understanding of the system.
- *Near-surface lithostratigraphy:* Primary – the lithology of the aquifer needs to be described because the assessment context requires that the aquifer is considered as part of the biosphere system in this Example.
- *Water bodies:* Primary – the assessment context specifies that an aquifer capable of supplying water of potable quality is to be considered as part of the biosphere system. There is a need to describe the characteristics of the aquifer (flow field, mineralogy, accessibility) in such a way as to provide an interface with geosphere models and to ensure consistency with domestic use.

The assessment context specifies that biosphere system change need not be considered. A constant biosphere system based on present-day conditions can therefore be assumed. No further steps are therefore required in implementation of the approach for identifying and justifying biosphere systems.

### C2.6.3. Biosphere system description for ERB1B

It is noted that a dominant consideration in defining the biosphere system for this Example is the local flow field within the aquifer in the vicinity of the release from the geosphere and the well. The flow field at any particularly location may be influenced by a large number of other attributes of the wider biosphere system, but only in so far as such factors determine the rates of recharge, abstraction and discharge from the aquifer. Hence, whereas such factors will be relevant to a detailed overall understanding of the system, they are not necessarily fundamental to the detailed system description required for biosphere assessment.

#### *C2.6.3.1. Anthropology/sociology*

*Population and community description*

A description of the local population structure (e.g. the size of the community, its use of local resources, etc.) is relevant to the biosphere system description, in so far as such factors can have an effect on water use. The influence of local water use on aquifer recharge and discharge may, in turn, affect water flow characteristics. However, it is relevant to note that, in practice, site-specific factors can be a major determining factor on local community structures. For example, in certain situations (e.g. high volume flow in the aquifer, combined with suitable terrain) it is possible that abstraction could be intended to serve a large population. In other situations, site-specific circumstances (remote location, difficult terrain, etc.) may dictate that only a small community (perhaps a small farm or temporary camp) could be supported on a sustainable basis.

It can be inferred from the assessment context that technological development is sufficient to allow for abstraction of water to take place. The actual level of technology required would depend on the specific situation in which abstraction takes place. Simple excavation into a shallow aquifer requires less technology than pumping from a borehole drilled into a deep, relatively impermeable, formation.

Consideration of local community structures will influence decisions made in respect of water demand, but may also be implicit in other basic assumptions adopted regarding the biosphere system and/or exposure groups. For example, a small, remote (or even temporary) community may be less likely to invoke complex water storage and distribution systems prior to use, whereas industrialised abstraction for a larger population might involve more sophisticated technologies.

Population size must be such that flow fields in the aquifer – including the effects of abstraction – are time-invariant in the long-term, although short-term fluctuations may occur because of variations within the envelope associated with a 'constant' climate. Sustainability considerations will also place a ceiling to the amount of perturbation on the aquifer caused by human actions. Moreover, the overall community context (combined with local lithostratigraphy) may affect the type of well that is constructed, and hence the potential (as well as the realised) abstraction rates in any given situation. Postulation of a particular abstraction rate will constrain the type of well that can be used and the community that can be supported.

*Human habits*

Human activities that are relevant to providing a description of the biosphere system are those which relate to the influence of human action on the biosphere. For this example, these are already explicitly addressed under 'Land Use' and 'Use of Water Resources', below. The detailed description of human habits is therefore considered irrelevant to the biosphere system description. It is nevertheless recognised that consideration of habits (i.e. what individual people do and how much time they spend doing it) is relevant to the characterisation of potential exposure groups, particularly in terms of defining their water consumption.

*Human diet*

Aspects of diet that are pertinent to the description of the biosphere (total consumption, fraction derived locally) are considered to be adequately addressed under 'Land Use' and 'Use of Water Resources', below. Broader considerations of 'Human Diet' are therefore considered irrelevant to the biosphere system description.

Whereas a detailed description of human diet is not important to the biosphere system description for the present Example, the fact that water is a part of human diet is clearly directly relevant to the overall assessment. The existence of a potable groundwater supply therefore needs to be recognised in the system description. Moreover, the presence of trace elements in the diet might be important in determining the turnover of radioactive isotopes in the human body and may therefore be relevant to the exposure assessment. For example, consideration of such issues could (in principle) contribute to the selection of data to support the calculation of ingestion doses.

*Land use*

Consideration of community land use is relevant to the biosphere system description, in so far as it may have an effect on water demand from, or recharge to, the aquifer.

*Use of water resources*

This characteristic of human behaviour is fundamental to the overall assessment context and is therefore highly relevant to the biosphere system description. It is noted that the assessment context restricts consideration to the use of well water for domestic supply only, thereby excluding agriculture and horticulture (e.g. irrigation), recreation (e.g. supply for swimming pools) and industry. The total volume of water withdrawn from the aquifer and used by the community is fundamental to the biosphere system description.

No guidance is provided in the assessment context with respect to the disposal of wastewater (or sewage sludge). This could potentially be an important transfer route for some radionuclides, for example if wastewater (or sewage sludge) were used to support gardening or agriculture (not a totally unreasonable expectation). However, although this possibility is noted, it is expected that the use of water for such purposes will be encompassed in later Examples and can therefore be excluded here. Hence, it will be assumed for the purposes of the Example 1B that contaminated wastewater simply 'disappears' from the domain of the biosphere system.

Although deliberate water treatment prior to consumption is explicitly excluded by the assessment context, certain passive processes (e.g. sorption, sedimentation) occurring during distribution and storage could potentially be relevant for some radionuclides.

*Physiological characteristics*

A detailed description of human physiological characteristics is not relevant to the biosphere system description for the present Example, although it may need to be considered in the characterisation of exposure groups (see Section C4.4).

Those aspects of human physiology that are pertinent to the biosphere system description are the factors influencing dietary intake and hence the overall exploitation of local resources by the local community. However, such considerations are already addressed under consideration of 'Land Use' and 'Use of Water Resources' (see above). It is therefore concluded that consideration of 'Physiological Characteristics' is irrelevant to the biosphere system description to this Example.

*C2.6.3.2. Climatology*

*Climate characteristics*

Consideration of climate characteristics is relevant to providing a coherent overall description of the biosphere system, in so far as climate contributes to determining:

— recharge and discharge of the aquifer system;
— availability and quality of local surface water resources (and hence demands on aquifer use);
— evaporative losses during storage of domestic water;
— water requirements (particularly water consumption) of the local community.

The 'cautious' approach dictated by the assessment context requires that the aquifer should be assumed the only source of drinking water for the exposed group.

*Temporal variability of climate*

The assumed assessment context for this Example specifies no biosphere change, and requires that water consumption should be consistent with a Temperate environment. Nevertheless, shorter-term variability (e.g. on inter-annual and decadal timescales) may be relevant both to the radiological assessment (via its effect on annual average water consumption) and as a contribution to fluctuations in the aquifer flow field. Nevertheless, it is not considered that detailed characterisation of climate variability will be important to the development of a biosphere model.

*Spatial variability of climate*

The region of interest to radiological assessment is limited to the aquifer and the well from which the contaminated water is assumed to be abstracted, together with any distribution system for water used by the community. However, because climate will influence the recharge the aquifer system, spatial variability in climate could be relevant if the climate characteristics at the zone of recharge were different from those in the region where the water is abstracted.

*Factors determining climate*

The assessment context specifies no biosphere change, and requires that water consumption should be consistent with a Temperate environment. Therefore there is no need to consider factors that determine climate as part of the biosphere system description, except in so far as the may contribute to uncertainty in parameter values relevant to Temperate conditions. Factors determining climate are therefore considered irrelevant.

*C2.6.3.3. Ecology*

*Ecosystems*

The assessment context restricts radiological considerations to the use of well water for domestic supply only, and precludes consideration of radiological exposure pathways other than drinking water from the well. However, ecosystems that are present in regions of aquifer recharge and discharge may, via their moderating influences of evapotranspiration and interception of precipitation, have an influence on the sub-surface flow field. In addition, local ecosystems in the vicinity of the community making use of the well may influence the availability of local water resources, and hence the demand for water abstraction. The types of ecosystems that may be present (whether terrestrial, aquatic or wetland), and the ways in which they are managed, are therefore relevant to a detailed understanding of overall patterns of recharge, abstraction and discharge for a particular location.

*Community description*

Information regarding the extent and heterogeneity of plant system components of ecosystems (e.g. deep-rooted trees) is relevant to the development of a detailed understanding of factors affecting recharge and discharge of the aquifer.

*C2.6.3.4. Geology/geomorphology/edaphology*

*Consolidated/solid geology*

Characteristics of the solid geology affecting flow rate in the saturated zone may be important factors controlling flow rate within the aquifer system. They may also govern the route, and rate, of natural recharge and discharge. Such characteristics will therefore be relevant to an overall understanding of the biosphere system for this Example. However, geological characteristics associated with long-term change of the aquifer system (erodability, actors affecting fault movement, etc.) are precluded by the assessment context, which specifies no biosphere change.

*Unconsolidated/drift geology*

The aquifer is unlikely to be located in unconsolidated sedimentary formations, but this possibility cannot be discounted. Hence, the characteristics of this region may include factors relevant to determining flow patterns (as well as recharge and discharge) within the aquifer system.

*Soils*

Different soils that are present in regions of aquifer recharge and discharge will moderate the rates of recharge and discharge of the aquifer system to differing extents. In addition, the soils are related to and, in some cases, may control the ecosystems that develop in such regions. Although not necessarily fundamental to the biosphere system description required for assessment purposes, characterisation of the types of soils that are present is relevant to a detailed understanding of overall patterns of recharge and discharge for a particular location.

*C2.6.3.5. Hydrology/hydrogeology/glaciology/geochemistry*

*Surface water bodies*

The presence of surface water bodies, particularly in regions of aquifer recharge, may have an influence on the sub-surface flow field. In addition, local surface water bodies in the vicinity of the community making use of the well will influence the availability of local water resources, and hence the demand for water abstraction. A description of the water bodies present at certain locations is therefore relevant to a detailed understanding of the flow system.

*Subsurface water bodies*

The variably saturated zone may have a moderating influence on rates of aquifer recharge and discharge and is therefore relevant to detailed representation of the flow system. However, it is not directly part of the system relevant to biosphere assessment, which is limited to the region of the aquifer encompassing the release and the well from which the contaminated water is assumed to be abstracted.

The presence of an aquifer is clearly fundamental to the assessment context and is therefore directly relevant to the biosphere system description. Adjacent aquitards are also relevant in so far as they define the boundaries of the aquifer (determining whether it is confined, unconfined or 'perched') and will therefore have an influence on the rates of aquifer flow, recharge and discharge.

*Ice sheets*

Consideration of a Temperate climate regime limits the potential importance of ice sheets. However, if there is significant spatial variability of climate between the location of water abstraction and the region of aquifer recharge, the presence of corrie and/or valley glaciers may be relevant.

*Water body characteristics*

The subsurface flow pattern within the aquifer is fundamental to the biosphere system description. Factors affecting this flow pattern include: the geometry of surface and subsurface water bodies, water flows in surface water systems and in the variably saturated zone, sea level (in so far as the aquifer discharge may be determined by the location of the coast), water inputs and water abstraction from the saturated zone. All these factors are therefore relevant to the biosphere system description.

Other potentially relevant characteristics of the water within the aquifer include the content and composition of suspended sediment and its chemical composition. Such factors could influence the potability of the supply and the presence of trace elements, which may have an impact on radiological exposures.

### C2.6.4. Summary of biosphere system description for ERB1B

The attributes deemed to be 'relevant' or 'potentially relevant' to a comprehensive description of the biosphere system relevant to ERB1B are therefore identified as follows:

- community description (in so far as it affects domestic water demand and hence abstraction rate);
- water as a part of human diet;
- community land use (in so far as it may affect local recharge and/or abstraction rate);
- use of water for domestic purposes obtained by abstraction from well intruding into a sub-surface aquifer;
- water distribution and storage prior to domestic use;
- characteristics of a temperate climate;
- temporal variability of temperate climate on interannual or decadal timescales;
- spatial variability of climate characteristics (in so far as climate may differ in regions of aquifer recharge and/or discharge);
- type of ecosystems that are present (in so far as they may influence aquifer recharge and discharge, as well as demand for abstraction);
- management of ecosystems (in so far as it may influence characteristics of aquifer recharge);

- extent and heterogeneity of components of plant communities (in so far as they may affect aquifer recharge characteristics);
- characteristics of consolidated/solid geology (except erodability);
- characteristics of unconsolidated/drift geology (except erodability and deposition rates);
- soil characteristics (in so far as they may affect water balance in the aquifer);
- surface water bodies (in so far as they may affect water balance in the aquifer);
- variably saturated zone (in so far as it may affect water balance in the aquifer);
- subsurface aquitard (in so far as it may determine boundaries and boundary conditions for flow within the aquifer);
- subsurface aquifer;
- corrie and valley glaciers (except flow of ice and development/retreat) (in so far as they may affect aquifer recharge characteristics);
- geometry of subsurface aquifer (including effects of sea level, where relevant);
- physical (e.g. suspended sediment load) composition of aquifer water;
- freeze/thaw phenomena in surface flow (in so far as they may affect water balance in the aquifer);
- subsurface flow in variably saturated zone (in so far as it may affect water balance in the aquifer);
- subsurface flow within the aquifer;
- chemical composition of aquifer water, including water/solid interactions, pH and Eh;
- water inputs to – and discharge from – the aquifer system;
- water abstraction from the saturated zone.

This list is generally consistent with the primary components identified earlier (identification and justification of biosphere systems). Most of the relevant and potentially relevant features fall under the general headings of Human activities, Climate, Near-surface lithostratigraphy and Water bodies. Geographical extent was also previously identified as an important principal component of the biosphere system. This has been addressed in the description of biosphere attributes through consideration of the way in which the assessment context determines the domain of the biosphere system of interest. Certain attributes that lie outside this domain (e.g. those related to Flora and fauna) are nevertheless deemed to be relevant in so far as they will, in practice, serve to control water balance within the aquifer.

As with ERB1A, the system adopted here is to represent dependencies between each of the biosphere system attributes identified above using an 'Interaction Matrix' approach. Unlike ERB1A, however, it is considered impractical to attempt to incorporate each of the 27 items above directly as leading diagonal elements of an interaction matrix.

A preliminary review is therefore undertaken in order to separate those attributes that can simply be considered as controlling factors on primary features of the biosphere system. In particular, a large number of attributes are considered relevant only in so far as they may influence aquifer recharge and/or discharge, or the demand for abstracted water. Provided that recharge, discharge and abstraction are explicitly accounted for in the overall system description, such attributes can therefore be considered to lie outside the system domain of interest – thereby essentially acting as external 'data drivers'. Hence the following attributes are considered to be ‘implicit’ in the system description in so far as they exert influences on the sub-surface flow field via water input, discharge and abstraction:

- community description (size, location, etc.);
- community land (and water) use;
- spatial variability of climate;
- temporal variability of climate;
- ecosystem type;
- management of ecosystems;
- extent and heterogeneity of components of plant communities;
- soil characteristics;
- surface water bodies;
- variably saturated zone;
- corrie and valley glaciers;
- freeze/thaw phenomena in surface flow;
- subsurface flow in variably saturated zone.

Furthermore, it is noted that certain other attributes identified as relevant are strictly ‘characteristics’ of particular features of the biosphere system. As such, they do not necessarily need to be represented explicitly in an ‘influence diagram’ representation of the biosphere system of interest. Relevant characteristics include:

- climate characteristics (temperature, precipitation, etc.);
- characteristics of consolidated and unconsolidated geology (i.e. lithostratigraphy, fracture systems and degree of weathering), in so far as these are relevant to defining aquifer properties;
- geometry of the aquifer;
- sediment composition and load in aquifer water;
- flow regime within the aquifer;
- chemical composition of aquifer water.

Interrelations and dependencies between the remaining fundamental attributes of the biosphere system are summarised in the form of an Interaction Matrix, as shown in Figure C4. It is emphasised that ‘implicit’ attributes of the system description and relevant ‘characteristics’ of biosphere system features are not screened out from further consideration; indeed, it is recognised that these aspects may need to be considered in more detail in when defining model parameter values.

The relevant characteristics of the leading diagonal elements of the Interaction Matrix shown in Figure C4 therefore include:

| LDE | Characteristics | ‘Implicit’ Attributes |
|---|---|---|
| Climate Temperature | Spatial variability of climate<br>Precipitation<br>Wind speed and direction<br>Solar radiation | <br>Interannual and decadal variability |
| Aquifer/aquitard | Geometry | |

| | | |
|---|---|---|
| | Lithostratigraphy<br>Fracture systems<br>Degree of weathering<br>Flow regime | |
| Water input | Sediment composition<br>Chemical properties<br>Flow rate | Community land and water use<br>Ecosystem types/management<br>Plant community characteristics<br>Soil characteristics<br>Surface water bodies<br>Variably saturated zone flows<br>Corrie and valley glaciers<br>Freeze/thaw phenomena |
| Water discharge | Flow rate | Community land and water use<br>Ecosystem types/management<br>Plant community characteristics<br>Soil characteristics<br>Surface water bodies<br>Variably saturated zone flows |
| Water abstraction | Flow rate | Community size/location<br>Community land and water use |
| Water properties | Suspended sediment load<br>Suspended sediment composition<br>Chemical composition<br>Water/solid interactions<br>pH and Eh | |
| Water storage | Suspended sediment load<br>Suspended sediment composition<br>Chemical composition<br>Water/solid interactions<br>pH and Eh | |
| Drinking water | Suspended sediment load<br>Suspended sediment composition<br>Chemical composition | |

It is relevant to note that the ranking of the LDEs within this particular representation is not considered especially important – the aim of using a matrix approach is simply to ensure that all potentially significant relationships are explicitly considered. However, it is also pertinent to note at this stage that use of an Interaction Matrix to represent associations between relevant biosphere system attributes differs from its application in model development. The process of relating the system description to a conceptual representation of the system as a basis for modelling is described in detail in Fig. C4.

### C2.6.5. Model development for ERB1B

#### *C2.6.5.1. Conceptualisation of biosphere system description*

For the biosphere system relevant to this Example, summarised in Figure C4, the following additional external factors can be identified:

- climate characteristics (Temperate) (including spatial and temporal variability);
- aquifer geometry (in terms of its influence on the flow system);
- aquifer recharge and discharge;
- community abstraction of water (in terms of its influence on the flow system).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Climate (temporal variability affects climate in a given year)** | | Climate properties in zone of recharge will affect input | Influence on flow boundary conditions in discharge zone | Temperature etc. will affect the volume of water required by the community | May have some influence on water quality, but is time invariant | Variability may be relevant factor in determining need for storage | |
| | **Aquifer/ Aquitard (geometry defines the flow system)** | Infiltration rate affected by hydraulic properties of system | Discharge rate affected by hydraulic properties of system | Determines the quantity and quality of available water at point of abstraction | Properties of geological system affect water characteristics | | |
| | Affects flow regime, chemistry etc. in subsurface features | **Water Input to Aquifer System (Recharge)** | | | | | |
| | Affects flow regime | | **Discharge from the Aquifer System** | Determines surface water bodies and hence availability of local supplies | | | |
| | May perturb natural flow regime | | | **Abstraction of Water from the Aquifer for Domestic Use** | Could cause physical, chemical or biological changes | Can't store or distribute water until it has been abstracted | Drinking water supply comes from abstraction (defined by context) |
| | Properties of water affect characteristics of geological system | | | Physical and chemical changes may affect actual abstraction rate | Physical and Chemical Properties of Aquifer Water | | Water must be potable to be used in drinking supply |
| | | | | | | **Water Storage and Distribution** | May affect quality of water supply |
| | | | | | | | **Drinking Water Supply** |

*FIG. C4. Interaction Matrix representation of associations and influences between Primary Attributes of the biosphere system for ERB1B.*

Such factors are therefore retained as issues to be addressed in modelling, but only in so far as they may influence significant model parameter values. In particular, it is recognised that they may each have an important influence on the assumed flow system within the aquifer or (for radiological assessment) on the consumption rate of drinking water.

Relevant physical features of the biosphere system are:

— water in the saturated zone;

— water supply delivered at the well head; and

— water supply delivered to consumers.

A decision is made to differentiate between these features in order to allow for potential changes to the physical and chemical characteristics of the water supply that may occur during abstraction, distribution and storage.

In considering radioactive contamination, the relevant characteristics of the physical features of the biosphere system (i.e. the source and supply of water) must be augmented to account for the presence of radionuclides. Relevant characteristics of exposure groups include their habits, physiological behaviour and, of course, the dose that they are assumed to incur. The leading diagonal elements of the 'complete' Interaction Matrix relevant to radiological assessment modelling can therefore be summarised as follows:

| System Feature (LDE) | Relevant Characteristics |
|---|---|
| Radionuclide source (1,1) | Spatially distributed flux (Bq $y^{-1}$)<br>Chemistry and hydrology at interface with the aquifer system |
| Water in saturated zone (2,2) | Radionuclide concentration field<br>(Volume flow)<br>Chemical composition/concentration field<br>Spatial distribution of physical properties<br>Spatial distribution of biological composition |
| Water at well head (3,3) | Radionuclide concentration<br>Physical, chemical and biological composition<br>(Volume flow) |
| Water supplied for drinking (4,4) | Radionuclide concentration<br>Physical, chemical and biological composition<br>(Volume flow) |
| Exposure group (5,5) | Consumption rate of drinking water<br>Stable element components of diet<br>Age<br>Annual individual effective dose |

The contaminated biosphere system can now be expressed in the form of an Interaction Matrix, as shown in Figure C5.

At this stage, the ODEs of the Interaction Matrix related to relevant radionuclide transport and exposure processes within the biosphere system are described in summary form only. The next step in the process of developing the conceptual model is therefore to amplify these descriptions to include all possibly relevant Features, Events and Process. This is achieved by screening against a comprehensive, independent FEP-list (see Annex BIV of Part B), taking into account the overall assessment context. A complete record of the screening process for ERB1B, summarising the various screening arguments, is provided in Table C4. The results of the screening exercise are summarised in a revised version of the Interaction Matrix, as shown in Figure C6.

| | | | |
|---|---|---|---|
| **Radionuclide Source** | Contamination from geosphere | | |
| | **Water in Saturated Zone** | Abstraction | |
| | | **Water at Well Head** | Storage and distribution |
| | | | **Water Supplied for Drinking** |

*FIG. C5. Summary representation of the radionuclide transport and exposure pathways relevant to radiological assessment modelling for ERB 1B.*

| | | | | |
|---|---|---|---|---|
| Radionuclide Source | Interception of release, advection and dispersion, surface reactions, physical, chemical and biological transformation | | | |
| | Water in Saturated Zone | Abstraction of water, physical (e.g. outgassing, temperature change), chemical and biological transformation, surface reactions | | |
| | | Water at Well Head | Storage and distribution, microbial action, evaporation and/or degassing, sedimentation and remobilisation, chemical change, adsorption and/or desorption, removal of sediment. | |
| | | | Water Supplied for Drinking | Water consumption (with suspended sediment), preparation of water-based drinks |
| | | | | Exposure Group |

*FIG. C6. Interaction Matrix representation of the radionuclide transport and exposure pathways for ERB 1B, including results of the FEP screening process.*

TABLE C4. RECORD OF FEP SCREENING FOR EXAMPLE 1B

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 1 | Assessment context | Y | Assessment Context issues are addressed in Section C3.1 of the Report |
| 2 | Biosphere system features | Y | See discussion below |
| 2.1 | Climate | Y | Included, but as external influence |
| 2.1.1 | Description of climate change | N | Precluded by Assessment Context |
| 2.1.2 | Climate categorisation | Y | Characteristics of Temperate climate and their spatial/temporal variability as external influences on biosphere system |
| 2.2 | Human society | Y | Addressed in so far as the exploitation and distribution of water resources is fundamental to the system definition |
| 2.3 | Systems of exchange | Y | Considered as external influences on rates of recharge/discharge/abstraction. Also biota within water distribution system |
| 2.3.1 | Environment types | Y | Not specified – but wide range of human influences is considered to be relevant |
| 2.3.2 | Ecosystems | Y | Not specified – but wide range potentially relevant to recharge/discharge/abstraction |
| 2.3.2.1 | Living components of ecosystems | Y | Microbial communities may influence contaminant behaviour in the water supply system |
| 2.3.2.2 | Non-living components of ecosystems | Y | Soils/variably saturated zone relevant to recharge/discharge. Also includes water supply, distribution and storage system |
| 3 | Biosphere events and processes | Y | See discussion below |
| 3.1 | Natural events and processes | Y | See discussion below |
| 3.1.1 | Environmental change | N | Precluded by assessment context |
| 3.1.2 | Environmental dynamics | Y | Implicitly included in choice of parameters via influence of external drivers (including recharge/discharge) |
| 3.1.2.1 | Diurnal variability | N | Not relevant to annual average water use and/or consumption |
| 3.1.2.2 | Seasonal variability | N | Not relevant to annual average water use and/or consumption |

TABLE C4. RECORD OF FEP SCREENING FOR EXAMPLE 1B (CONTINUED)

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 3.1.2.3 | Interannual and longer timescale variability | Y | May influence contamination/intake of water in any given year – also potential impact on requirements for water storage |
| 3.1.3 | Cycling and distribution of materials in living components | Y | See discussion below |
| 3.1.3.1 | Transport mediated by flora and fauna | Y | Transpiration, interception etc. by plants control infiltration as external influences on system (recharge and discharge) |
| 3.1.3.2 | Metabolism by flora and fauna | Y | Microbial metabolism may affect water characteristics in supply system |
| 3.1.4 | Cycling and distribution in non-living components | Y | See discussion below |
| 3.1.4.1 | Atmospheric transport | Y | Possibility of evaporation and/or degassing during storage/distribution |
| 3.1.4.2 | Water-borne transport | Y | Flow field in aquifer relative to spatially distribute r/n release is fundamental to determining concentrations in water |
| 3.1.4.2.1 | Infiltration | Y | Included as an assumed external influence on water flow in aquifer |
| 3.1.4.2.2 | Percolation | Y | Included as an assumed external influence on water flow in aquifer |
| 3.1.4.2.3 | Capillary rise | Y | Evaporation/transpiration potentially relevant to net water balance |
| 3.1.4.2.4 | Groundwater transport | Y | Flow system in saturated zone is fundamental to determining concentrations in abstracted water |
| 3.1.3.2.5 | Multiphase flow | N | No direct relevance to this Example |
| 3.1.3.2.6 | Surface run-off | Y | Included as an assumed external influence on water flow in aquifer |
| 3.1.3.2.7 | Discharge | Y | Included as an external influence on flow field in the aquifer |
| 3.1.3.2.8 | Recharge | Y | Included as an external influence on flow field in the aquifer |
| 3.1.3.2.9 | Transport in surface water bodies | N | Surface water bodies are relevant only in terms of effect on aquifer flow boundary conditions |
| 3.1.3.2.10 | Erosion | N | May be implicit in specification of sediment load, but otherwise not relevant |

TABLE C4. RECORD OF FEP SCREENING FOR EXAMPLE 1B (CONTINUED)

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 3.1.4.3 | Solid-phase transport | Y | Some processes may serve to change characteristics of the water supply – see discussion below |
| 3.1.4.3.1 | Landslides and rock falls | N | Not relevant |
| 3.1.4.3.2 | Sedimentation | Y | Settling of suspended sediments in the water distribution/storage system |
| 3.1.4.3.3 | Sediment suspension | Y | Remobilisation of sediment during periodic maintenance of supply system |
| 3.1.4.3.3 | Rain splash | N | Not relevant to this Example |
| 3.1.4.4 | Physicochemical changes | Y | Some processes may serve to change characteristics of the water supply – see discussion below |
| 3.1.4.4.1 | Dissolution/precipitation | Y | Possibility of passive chemical transformation in well or within water supply system |
| 3.1.4.4.2 | Adsorption/desorption | Y | Potentially relevant to r/n concentration if there are changes in sediment load, or as surface reactions within the well. |
| 3.1.4.4.3 | Colloid formation | N | Does not affect the determination of r/n concentration in bulk water |
| 3.2 | Events and processes related to human activity | Y | See discussion below |
| 3.2.1 | Chemical changes | N | 'External' human actions may affect water quality in aquifer system – infiltration etc. |
| 3.2.2 | Physical changes | Y | Abstraction of water could influence flow field in the aquifer |
| 3.2.3 | Recycling and mixing of bulk materials | Y | See discussion below |
| 3.2.3.1 | Ploughing | N | Not relevant |
| 3.2.3.2 | Well supply | Y | Fundamental to the assessment context |
| 3.2.3.3 | Other water supply | Y | Possible external influence on community demand for abstracted water and hence flow field in aquifer |
| 3.2.3.4 | Irrigation | Y | Possible influence on infiltration and net water balance |

TABLE C4. RECORD OF FEP SCREENING FOR EXAMPLE 1B (CONTINUED)

| FEP Identifier | FEP Name | Included (Y/N)? | Comments |
|---|---|---|---|
| 3.2.3.5 | Recycling of bulk solid materials | N | Not relevant to this assessment context |
| 3.2.3.6 | Artificial mixing of water bodies | N | Not relevant to this assessment context |
| 3.2.3.7 | Dredging | N | Periodic cleaning/dredging of water supply and distribution system? |
| 3.2.3.8 | Controlled ventilation | N | Not relevant to this assessment context |
| 3.2.4 | Redistribution of trace materials | Y | No deliberate processing of water supply, but passive changes may occur (e.g. in preparation of drinks) |
| 4 | Human exposure Features, Events and Process | Y | See discussion below |
| 4.1 | Human habits | Y | See discussion below |
| 4.1.1 | Resource usage | Y | Exploitation of water resources implicit in system description; other resources excluded by assessment context |
| 4.1.2 | Storage of products | Y | Water may be stored in distribution system prior to consumption |
| 4.1.3 | Location | N | Not relevant |
| 4.1.4 | Diet | Y | Stable element components of diet may be relevant in determining exposures for some radionuclides |
| 4.2 | External irradiation | N | Excluded by assessment context |
| 4.3 | Internal exposure | Y | See discussion below |
| 4.3.1 | Inhalation | N | Excluded by assessment context |
| 4.3.2 | Ingestion | Y | Consumption of contaminated water (including suspended sediment) as supplied, or in water-based drinks etc. |
| 4.3.3 | Dermal absorption | N | Excluded by assessment context |

### C2.6.6. Conceptual model development

A conceptual model for the purposes of radiological assessment is now developed from the 'complete' Interaction Matrix shown in Figure C6. The first step in this process is to identify whether or not screening arguments can be developed for discarding FEPs shown in the matrix, for example by making approximating assumptions (taking into account the required 'cautious' nature of the assessment).

Based on the arguments previously developed in respect of ERB 1A, it is concluded that the FEPs associated with the storage and distribution of water to consumers can be neglected. Similar arguments can be applied in respect of those FEPs related to physical, chemical and biological transformations that may take place during abstraction via the well. As a general rule, therefore, it should be possible to exclude such FEPs from further consideration, recognising that such uncertainties exist when the results are eventually applied.

The decay and ingrowth of radionuclides during transport through the biosphere system could potentially affect the equilibrium concentrations of certain short-lived radioactive progeny in the drinking water supply. Given that the model is intended to be generically applicable, it will not be appropriate to include explicit representation of transport through the abstraction and distribution system. However, it will be cautious to assume that short-lived progeny (i.e. those with half-lives comparable with, or less than, the mean time spent by water in the aquifer and distribution network) are present in the drinking water supply in equilibrium with their parents, whatever the original concentrations may have been at the well head.

In the light of the above, it should again be possible to ignore in conceptual model development those processes associated with: (a) the water abstraction system (except in so far as it influences the flow regime in the aquifer); (b) the storage and distribution network; or (c) the preparation of water-based drinks. By contrast with ERB1A, however, the bulk concentration of radionuclides in water delivered at the well head ($C_{well,i}$) needs to be calculated, based on the source term provided as input from the geosphere modelling. The biosphere model therefore needs to represent the interception, advection and dispersion of the released flux of radionuclides into the aquifer and their transport to the well.

In developing a conceptual description of the processes associated with the calculation of $C_{well,i}$, it is helpful to expand briefly on some of the entries in Figure C6. Thus:

- The term 'interception' is used to mean the intersection and capture of the radionuclide plume at the base of the aquifer. This should not be confused with the interception of precipitation by vegetation.
- Dispersion within the aquifer includes both diffusion and hydrodynamic dispersion, including (if appropriate) rock matrix diffusion.
- Surface reactions of radionuclides include sorption.
- Chemical transformation of radionuclides includes both changes of species in the aqueous phases and precipitation/dissolution reactions.
- Physical transformation includes radioactive decay.
- The term 'storage' is used only in the sense of storage of abstracted water (e.g. in cisterns). Aquifer storage is implicit in the definition of the aquifer.

Water in the saturated zone is taken to be characterised by a 3-D radionuclide concentration field. In addition, it is also characterised by 3-D fields relating to its chemical, physical and biological composition. These 3-D fields are of limited spatial extent, defining the spatial domain of the aquifer considered for modelling purposes. It is assumed that these fields are deterministically defined, i.e. uncertainties in aquifer characteristics do not require application of a stochastic model to represent the structure of these fields. Integration of the fields over all, or part, of the domain, gives spatially averaged quantities that may be useful for modelling purposes. Thus, for example, integration of the interconnected porosity (a physical property) over the whole spatial domain gives the total volume of accessible aquifer water present.

Whereas water in the saturated zone is characterised by 3-D fields, water at the well head and water in domestic supply are both characterised by point measures. In each case, these measures were identified as radionuclide concentration; physical, chemical and biological composition; and volumetric flow rate.

### *C2.6.6.1. Hydrological modelling considerations*

In principle, the aquifer of interest can be either confined or unconfined. The discharges and interaction with surface water features for the two types of system are very different. For unconfined systems, the entire surface over the extent of the aquifer can, in principle, contribute to recharge and/or discharge. For confined systems, the area over which unimpeded recharge of the system can occur is limited by the presence of the confining layer.

Unconfined aquifers at or near the land surface (perhaps between 30 m and 200 m depth) are relatively easy to exploit as a water resource and are therefore more likely to be used on a local scale. By contrast, confined aquifers are often associated with large geological basin structures, or dipping layered strata, and can be very deep underground. Because of the technology and costs associated with their exploitation, abstraction of water from such systems is more generally carried out on a regional scale. Moreover, it might be anticipated that, in the context of total system performance assessment for deep geological waste disposal, regional-scale confined aquifer features would readily be incorporated into geosphere transport models. The desire to incorporate modelling of an aquifer as part of the biosphere model (as in this Example) is therefore perhaps more likely to be associated with near-surface, unconfined flow systems.

Nevertheless, conceptualisation of the flow system is somewhat easier for a confined aquifer. In what follows, cases for confined aquifers are discussed first and then some remarks are made as to how these cases would be modified when unconfined aquifers are considered.

Two general cases for confined aquifers may be conceived: (a) a monotonic hydraulic gradient, with essentially unidirectional flow from a recharge zone to a discharge zone; and (b) converging flow as a result of recharge from two separate areas with discharge via leakage through the overlying aquiclude. In either case, the water balance in the flow system within the zone of interest can be simply represented by:

$$Q_1 = Q_2 + Q_3 - Q_4$$

where:

$Q_1$ is the net recharge to the system from percolating waters (i.e. at the zone of recharge, but also from percolation through the overlying aquiclude) upstream of the region of interest;

$Q_2$ is the total discharge from the system (i.e. at the discharge zone, if it exists, but also including discharge through confining layers along spring lines, and losses resulting from abstractions) downstream of the region of interest;
$Q_3$ is the abstraction rate via the well;
$Q_4$ is the volumetric input from deeper groundwater beneath the aquifer.

Because the assessment basis for this Example specifies no biosphere change, the basic conceptual water balance considerations relevant to an unconfined aquifer can be considered to apply to a confined system. In a time-invariant system, it is not necessary to be concerned with fluctuations in the phreatic surface, and there is consequently no need to consider changes in aquifer storage with time.

*C2.6.6.2. Contaminant transport modelling considerations*

A schematic representation of the generalised transport regime within the aquifer is shown in Figure C7. Note that the geometry of this figure is stylised and that there is no implication that the system is horizontally stratified or that the aquifer is of constant thickness.

In general, the shape of the plume can be determined only by solution of the advection-dispersion equation for a single porosity, dual porosity or fractured system, as appropriate. Furthermore, the characteristics of the plume in the vicinity of the well of interest will be influenced by the abstraction rate from this or any other sources. Moreover, the confining aquiclude may not be present, as unconfined aquifers are also considered as part of the Example.

In addition to the dispersion regime within the aquifer, the source extent and source-well distances represent critical factors in determining the concentration field. Very different situations can be envisaged, depending on whether transport in the underlying geosphere is in a porous medium or through a few hydrologically significant fractures.

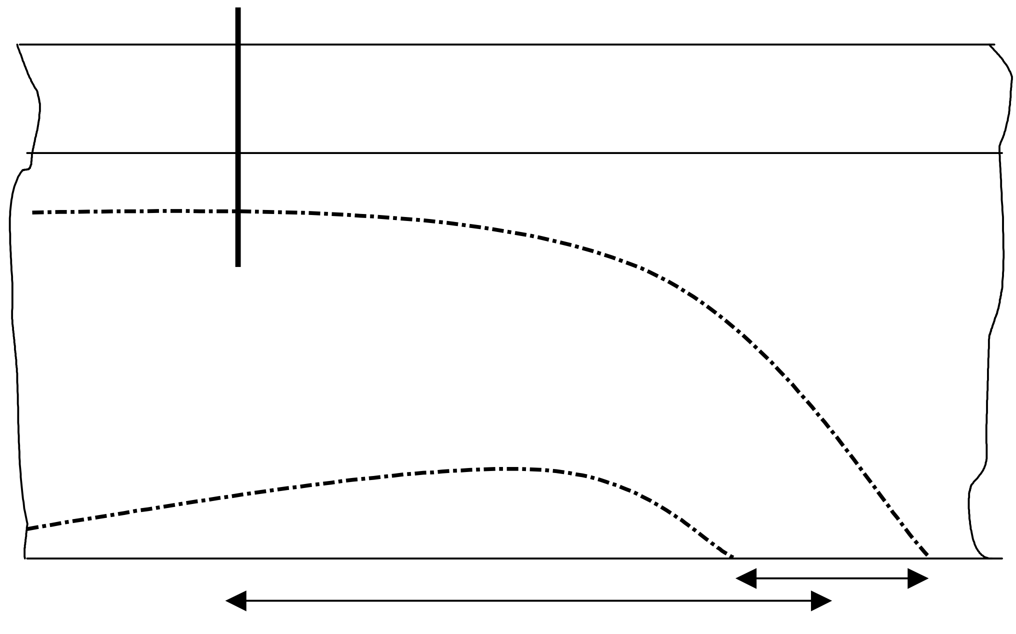

*FIG. C7. Generalised transport regime for release to an aquifer.*

### C2.6.7. Mathematical formalism

In order to derive a value for the bulk concentration of radionuclides in water delivered at the well head ($C_{well,i}$), mathematical formalisms are required for the following transformations:

- conversion of a spatially distributed flux of radionuclides entering the aquifer into a 3-D concentration field in the saturated zone;
- conversion of the 3-D concentration field in the saturated zone to a point source concentration of radionuclides in water at the well head.

*C2.6.7.1. Input flux to concentration field*

A wide range of potential considerations is relevant to the evaluation of radionuclide concentrations in the saturated zone. These include: the detailed spatial distribution of the radionuclide source, the chemistry and hydrology at the interface with the aquifer system, the configuration and flow field within the aquifer, and the distance from the source to the point of abstraction. The collective effect of all these processes on the concentration in the groundwater plume can be formally expressed (for a single-member decay chain) using the following transformation:

$$C_{w,i}(x,\theta) = A_{F,i}(x,\theta,x_0) * F_i(x_0)$$

where:

$C_{w,i}(x,\theta)$ is the concentration of radionuclide i at general location $(x,\theta)$ (Bq $m^{-3}$);
$A_{F,i}(x,\theta,x_0)$ is an aquifer transport factor, analogous to the atmospheric transport factor used in atmospheric dispersion calculations (y $m^{-3}$); and
$F_i(x_0)$ is the rate of release of radionuclide i into the aquifer (Bq $y^{-1}$).

The transformation can be readily extended to include the effects of radionuclide decay chains, as appropriate.

Taking account of the processes contributing to dilution, dispersion and other transformations within the aquifer, the transport factor can be decomposed in the following form:

$$A_{F,i}(x,\theta,x_0) = A_P * \phi_D * \phi_C * \phi_B$$

where:

$A_P$ represents the processes of physical dispersion (y $m^{-3}$);
$\phi_D$ represents radioactive decay;
$\phi_C$ represents the effects of chemical interactions; and
$\phi_B$ represents the effects of biological interactions.

In general, if the release configuration and flow field through the aquifer are known, $A_{F,i}(x,\theta,x_0)$ can be calculated using an appropriate version of the advection-dispersion equation with distributed sources and sinks to represent radioactive decay, chemical transformation and sorption reactions. In principle, all the terms on the right hand side of the equation in depend on the location with respect to the source. Also, it has been assumed that physical dispersion, radioactive decay, chemical interactions and biological interactions are independent terms. This is not necessarily always the case, e.g. when physical dispersion affects transit times from the source to the well and, therefore, affects the amount of radioactive decay that occurs.

If (adopting a cautious approach) radioactive decay is neglected, balance considerations imply that at equilibrium the rate at which activity leaves any region of the system must equal the rate at which activity enters that region. Furthermore, chemical and biological transformations can therefore be neglected if it assumed that: (a) the chosen dose coefficients correspond to the highest reasonable gut uptake factor for each radionuclide; and (b) short-lived daughter radionuclides are present in secular equilibrium with their parents. Similar assumptions were adopted for ERB1A in respect of simplifications related to possible chemical and biological transformation in the water storage and distribution system. Thus, a reasonable position to adopt for an equilibrium system, such as that considered in this Example, is that $\phi_D = \phi_C = \phi_B = 1$.

Attention therefore becomes focused on the estimation of physical dispersion. The degree of physical dispersion depends strongly on the geometry of the source in relation to the well and on the flow properties of the aquifer. General rules cannot be provided, but a number of special cases can usefully be analysed. Moreover, a generic expression of physical dispersion can be derived if certain simplifying assumptions are adopted in respect of physical dispersion:

— The radionuclide plume is intercepted by the well's zone of influence.

— Using a 'mixing cell' model, the average concentration at the well head is assumed to be proportional to the release rate divided by the effective flow rate, $Q$ ($m^3$ $y^{-1}$), in the 'dispersion volume' of the aquifer;

— $Q$ is not limited by the total volume of the aquifer, nor does it need to include the total volume flow within the aquifer;

Hence the aquifer transport factor is re-written in the following form:

$$A_{F,i}(x,\theta,x_0) = 1/Q$$

where $Q$ is determined by water balance considerations within the zone of interest.

Thus, it is assumed that radionuclides are released into the aquifer and mixed within a finite volume of water before entering the well's zone of influence. A general expression for the concentration of radionuclides in the aquifer water can then be derived, assuming that the release rate of radionuclides into the aquifer is given by:

$$F_i = C_{gw,i}\, Q_4$$

where:

$C_{gw,i}$ is the radionuclide concentration in groundwater entering the aquifer from the underlying geosphere. It is then possible to write:

$$C_{w,i} = C_{gw,i}\, Q_4 / (Q_4 + Q_1).$$

The primary issue determining concentration within the aquifer is then the size of the effective flow volume relative to the discharge volume from deeper groundwater. If the aquifer flow is dominated by flow generated recharge from outcrop, $Q_1$ will be much larger than $Q_4$ and the average concentration of radionuclides in the aquifer downstream from the point of release will be much lower than the concentration in waters discharged from the geosphere. However, there can be low dilution cases where aquifer waters are replenished mainly from underlying rocks, e.g. if potential upland recharge zones are sealed by low conductivity superficial deposits. In these cases, $Q_1$ may be much less than $Q_4$ and radionuclide concentrations in the aquifer will be similar to those in waters discharged from the geosphere.

An absolute worst case will therefore arise if all discharge downstream of the well's zone of influence (other than via abstraction from the well) is precluded (i.e. $Q_2 = 0$) from the dispersion estimate. The volume of water required by the community that makes use of the well ($Q_3$) then determines the total dilution. It is then possible to express the concentration in the aquifer itself as:

$$C_{w,i} = C_{gw,i}\, Q_4 / Q_3$$

with the limit $Q_4 \leq Q_3$.

When $Q_1$ is relatively small, the existence of a pumped well means that hydraulic heads will be lowered in the aquifer, causing a head gradient to exist between the aquifer and the underlying rocks. In this context, it is emphasised that the sinking of an artesian well into a reservoir of ancient waters is not unknown. However, it should also be noted that such a groundwater system would almost certainly not be sustainable on some timescale. The issue would then be whether that timescale is long compared with the timescale over which assessment calculations are to be carried out.

In defining values for the parameters used in the aquifer model, therefore, the effective mixing volume must be consistent with known information regarding the volume flow rate in the aquifer and the potential requirements of the community using the well. Values of $Q_1$ and $Q_2$ can typically be calculated using expressions of the form:

$$Q = A_{aq} K_{sat} (\Delta h / \Delta x)$$

where:

$Q$ is the flow rate of interest ($m^3 y^{-1}$);
$A_{aq}$ is the cross-sectional area of the aquifer perpendicular to the flow direction ($m^2$);
$K_{sat}$ is the saturated hydraulic conductivity in the direction of flow; and
$\Delta h / \Delta x$ is the hydraulic head gradient in the direction of flow.

*C2.6.7.2. Concentration field to concentration in well water*

The concentration in well water is an appropriate spatial average of the groundwater concentration field. Specifically:

$$C_{well} = \frac{\int_z F(z) C_w(z) W(z) dz}{\int_z F(z) dz}$$

where:

$F(z)$ is the flow of water into the well per unit depth ($m^2 y^{-1}$);
$C_w(z)$ is the concentration of the radionuclide in the aquifer water ($Bq\ m^{-3}$);
$W(z)$ is the degree to which the groundwater concentration of the radionuclide is modified during entry into the well bore; and
$z$ is the depth in the aquifer.

Typically, wells will be cased through the superficial cover and overlying aquiclude, and screened throughout much of their depth in the aquifer. It is noted that if $F(z)$ and $W(z)$ are independent of $z$ over the full depth of the aquifer, $C_{\text{well}}$ becomes the vertically averaged radionuclide concentration in aquifer waters at the location of interest. This emphasises that it may be adequate to consider the plume as well-mixed over the depth of the aquifer, even if mixing is not complete at the location of the well, as the well itself effectively acts as a depth-averaging sampler of water characteristics.

However, it is also likely that there will be circumstances in which the well does not penetrate the full depth of the aquifer. In that case, the primary issue is the degree of non-uniformity of mixing over the sampled zone. It should also be noted that, at equilibrium, balance considerations imply that $W$(z) will be approximately unity, unless radioactive decay in transit from the aquifer to the well bore is significant.

As in ERB1A, the underlying mathematical model for radiological assessment can then be considered as a proportional relationship between annual individual effective dose and the bulk concentration of radionuclides in water delivered at the well head. Thus:

$$H_{E,i} = C_{well,i} * I * dcf_i$$

where:

| | |
|---|---|
| $H_{E,i}$ | annual individual dose from radionuclide i (Sv $y^{-1}$); |
| $C_{well,i}$ | bulk concentration of radionuclide i abstracted water (Bq $m^{-3}$); |
| $I$ | consumption rate of drinking water ($m^3$ $y^{-1}$); |
| $dcf_i$ | dose coefficient for radionuclide i (Sv $Bq^{-1}$). |

Other considerations relevant to the evaluation of radiological impact are the same as those considered in respect of ERB1A.

### C2.6.8. Selection of data

All data considerations are as for ERB1A, except for the concentration of radionuclides delivered at the well head. This depends on characterisation of the aquifer and the hydrogeological connection with the geosphere below.

The assumed assessment context for this Example presents significant difficulties in respect of parameter choice to represent the aquifer. Because of major sensitivities to the configuration of the release, the assumed relative location of the well, and overall flow pattern within the aquifer, it is very difficult to conceive of generically applicable values to quantify aquifer features. A worst case will be achieved if it is simply (and highly pessimistically) assumed that all the release into the aquifer is captured by the well and diluted in the abstracted volume of water used by the community. At the other extreme, it might simply be assumed that the release is effectively diluted within the volume throughput of the confined aquifer of a geological basin. However, neither of these seems likely to represent a satisfactory assumption for most applications. Site-specific information, as well as coherent interfacing with the geosphere part of the performance assessment, should promote better understanding of the interception and dispersion of the release and help to provide an effective indicator of safety performance, but this can not apply to a generic assessment context.

Pinedo et al., (1999) have reviewed the assumed degree of 'dilution' that occurs at the interface between geosphere models and biosphere models in a range of repository performance assessments. The value assumed in any given assessment depends on how much dilution has already been taken into account within the geosphere model (effectively, where the interface has been located within the total system), as well as how much water is present in the biosphere system. In the study made by Pinedo et al., (1999), the effective dilution factors ranged from 1 to approximately $10^6$.

The approach of reducing modelling of the aquifer to a simple 'mixing cell' involves a range of highly simplifying assumptions, aggregating a large number of features that might normally be expected to be addressed individually within more complex models for groundwater transport. Nevertheless, participants in the BIOMOVS II model intercomparison exercise found it necessary to adopt such a method when presented with the problem of representing in their biosphere models an ill-defined release to a poorly-characterised aquifer (BIOMOVS II, 1996b). The same modelling approach is adopted here, with an 'effective dilution factor' of $10^4$ being chosen for calculation purposes. It is underlined that the generic nature of the assessment context for this Example Reference Biosphere dictates that such a choice wholly arbitrary.

Within practical, 'real' assessments, the particular choice adopted can be justified by reference to the geosphere modelling domain and boundary conditions. The location of an assumed well relative to the radionuclide plume is a critical factor. If only limited dispersion can occur between the release location and the well, it may be very pessimistic (unless the well's zone of influence is very large) to assume that the region of highest concentration is intercepted. Alternatively, if the plume experiences significant dispersion relative to the assumed abstraction rate from the well, it might be optimistic to assume that the entire plume enters the well's zone of influence. Again, the biosphere modelling assumptions would inevitably be better justified with reference to a specific site context.

## C2.7. RESULTS FOR ERB1

TABLE C5. INPUT DATA AND CALCULATED INDICATORS OF RADIOLOGICAL IMPACT FOR EXAMPLE REFERENCE BIOSPHERE 1A AND 1B

| Radionuclide | Consumption Rate ($m^3 y^{-1}$) | Dose Coefficient ($Sv\ Bq^{-1}$) | ERB1A Dose ($Sv\ y^{-1}$ / $Bq\ m^{-3}$) | ERB1B 'Dilution Factor' ($m^3 y^{-1}$) | ERB1B Dose ($Sv\ y^{-1}$ / $Bq\ y^{-1}$) |
|---|---|---|---|---|---|
| C-14 | 1.2 | 5.80E-10 | 6.96E-10 | 1.00E+04 | 6.96E-14 |
| Cl-36 | 1.2 | 9.30E-10 | 1.12E-09 | 1.00E+04 | 1.12E-13 |
| Ni-59 | 1.2 | 6.30E-11 | 7.56E-11 | 1.00E+04 | 7.56E-15 |
| Ni-63 | 1.2 | 1.50E-10 | 1.80E-10 | 1.00E+04 | 1.80E-14 |
| Se-79 | 1.2 | 2.90E-09 | 3.48E-09 | 1.00E+04 | 3.48E-13 |
| Sr-90* | 1.2 | 3.07E-08 | 3.68E-08 | 1.00E+04 | 3.68E-12 |
| Zr-93* | 1.2 | 1.22E-09 | 1.46E-09 | 1.00E+04 | 1.46E-13 |
| Nb-94 | 1.2 | 1.70E-09 | 2.04E-09 | 1.00E+04 | 2.04E-13 |
| Tc-99 | 1.2 | 6.40E-10 | 7.68E-10 | 1.00E+04 | 7.68E-14 |
| Pd-107 | 1.2 | 3.70E-11 | 4.44E-11 | 1.00E+04 | 4.44E-15 |
| Sn-126 | 1.2 | 4.70E-09 | 5.64E-09 | 1.00E+04 | 5.64E-13 |
| I-129 | 1.2 | 1.10E-07 | 1.32E-07 | 1.00E+04 | 1.32E-11 |
| Cs-135 | 1.2 | 2.00E-09 | 2.40E-09 | 1.00E+04 | 2.40E-13 |
| Cs-137 | 1.2 | 1.30E-08 | 1.56E-08 | 1.00E+04 | 1.56E-12 |
| Sm-151 | 1.2 | 9.80E-11 | 1.18E-10 | 1.00E+04 | 1.18E-14 |
| Ra-226* | 1.2 | 2.17E-06 | 2.61E-06 | 1.00E+04 | 2.61E-10 |
| Th-229* | 1.2 | 6.13E-07 | 7.36E-07 | 1.00E+04 | 7.36E-11 |

TABLE C5. (CONT.)

| Radionuclide | Consumption Rate ($m^3y^{-1}$) | Dose Coefficient ($Sv\ Bq^{-1}$) | ERB1A Dose ($Sv\ y^{-1}$ / $Bq\ m^{-3}$) | ERB1B 'Dilution Factor' ($m^3y^{-1}$) | ERB1B Dose ($Sv\ y^{-1}$ / $Bq\ y^{-1}$) |
|---|---|---|---|---|---|
| Th-230 | 1.2 | 2.10E-07 | 2.52E-07 | 1.00E+04 | 2.52E-11 |
| Th-232* | 1.2 | 1.06E-06 | 1.27E-06 | 1.00E+04 | 1.27E-10 |
| Np-237* | 1.2 | 1.11E-07 | 1.33E-07 | 1.00E+04 | 1.33E-11 |
| Pa-231* | 1.2 | 1.92E-06 | 2.30E-06 | 1.00E+04 | 2.30E-10 |
| U-233 | 1.2 | 5.10E-08 | 6.12E-08 | 1.00E+04 | 6.12E-12 |
| U-234 | 1.2 | 4.90E-08 | 5.88E-08 | 1.00E+04 | 5.88E-12 |
| U-235* | 1.2 | 4.73E-08 | 5.68E-08 | 1.00E+04 | 5.68E-12 |
| U-236 | 1.2 | 4.70E-08 | 5.64E-08 | 1.00E+04 | 5.64E-12 |
| U-238* | 1.2 | 4.84E-08 | 5.81E-08 | 1.00E+04 | 5.81E-12 |
| Pu-238 | 1.2 | 2.30E-07 | 2.76E-07 | 1.00E+04 | 2.76E-11 |
| Pu-239 | 1.2 | 2.50E-07 | 3.00E-07 | 1.00E+04 | 3.00E-11 |
| Pu-240 | 1.2 | 2.50E-07 | 3.00E-07 | 1.00E+04 | 3.00E-11 |
| Pu-242 | 1.2 | 2.40E-07 | 2.88E-07 | 1.00E+04 | 2.88E-11 |
| Am-241 | 1.2 | 2.00E-07 | 2.40E-07 | 1.00E+04 | 2.40E-11 |
| Am-243* | 1.2 | 2.01E-07 | 2.41E-07 | 1.00E+04 | 2.41E-11 |
| Cm-245* | 1.2 | 2.15E-07 | 2.58E-07 | 1.00E+04 | 2.58E-11 |
| Cm-246 | 1.2 | 2.10E-07 | 2.52E-07 | 1.00E+04 | 2.52E-11 |

* indicates where relatively short lived daughters have been included in the calculations, by assuming they are in secular equilibrium with the parent; i.e. the dose coefficient listed includes the contributions from the progeny concerned.

**Important Notes:**

(1) 'Dose' values listed above should be interpreted solely as indicators of potential radiological impact arising from the postulated contamination and exposure route, described in the assessment context.
(2) The consumption rate is based on the annual consumption rate of water, assuming that all supplies are derived from the contaminated well source. No other exposure pathways are assumed.
(3) The dose coefficients are those applying to adult members of the public.
(4) For Variant 1B, the 'dilution factor' is intended to be a realistic value, but has been arbitrarily selected from a very wide range. The actual value used in a particular assessment would need to be justified according to the characteristics of the release to the aquifer, the aquifer itself and the well.

## C3. EXAMPLE REFERENCE BIOSPHERE 2A, AGRICULTURAL WELL

ERB1 was developed from a very simple hypothetical assessment context, restricting consideration to a single transfer and exposure pathway. This, in turn, resulted in a simple conceptual and mathematical model, with very limited data requirements that are relatively easy to support and justify. However, ERB1 does not address directly the full range of issues that are usually judged to be relevant to radiation protection objectives, nor does it necessarily provide sufficient confidence that all the relevant issues have been considered. In particular, previous assessments have demonstrated that, in some circumstances, exposure pathways other than drinking water can dominate individual doses.

ERB2 is intended to address a wider range of multiple transfer and exposure pathways, assuming constant biosphere conditions. 'Constant' in this case means that characteristics of the principal components of the biosphere system are assumed to be invariant over the period in which contaminants released into the system achieve equilibrium concentration levels in environmental media. Since the delay from original disposal to the time when release may occur can be very long, and given that the subsequent release can occur over very extended periods, it is not clear that a constant biosphere based on present-day conditions at a particular site will be the most appropriate assumption.

However, the identification of a range of constant biospheres, based on present-day analogue systems, could in principle form the basis for representing the most relevant alternatives that could arise within the time frame of interest. Indeed, such variants could find a collective role, for example, within assessment approaches based on a non-sequential representation of system change (See discussion of biosphere systems in Section B3 of Part B).

ERB2 is developed through two cases, both of which are based on the assumption of an agricultural biosphere. ERB2A involves the assumption that water resources are obtained via a well drilled into the underlying regional aquifer. By contrast, ERB2B invokes more complex considerations by assuming a 'natural' release of contaminated groundwater. ERB2 is therefore capable of being explored in distinct variants that allow for alternative assumptions regarding basic features, such as climate characteristics and the geosphere-biosphere interface, to be considered.

A much wider range of constant biosphere systems supporting consideration of multiple pathways, based on alternative assumptions regarding land use and/or mode of release, could, in principle, also be considered. However, it has not been possible to incorporate such cases within the scope of the BIOMASS Theme 1 programme.

## C3.1. ASSESSMENT CONTEXT FOR ERB2A

For ERB2A, these aspects of the assumed Assessment Context can be summarised as:

| | |
|---|---|
| Assessment Endpoint: | Annual individual effective dose. |
| Assessment Philosophy: | 'Equitable' except with respect the critical group definition, which should invoke a 'cautious' approach. |
| Repository Type: | Deep repository for long-lived solid radioactive waste. |
| Site Context: | Generic inland repository, with aquifer at accessible depth. No biosphere change. |
| Geosphere/Biosphere Interface: | Well intruding into aquifer plume with abstraction at a rate consistent with domestic and agricultural use. Concentrations of radionuclides in the abstracted water (including relevant short-lived daughters) are provided by geosphere transport models. |
| Source Term: | Constant unit concentration maintained indefinitely for each radionuclide. Nb-94, Tc-99, I-129 and Np-237. Chosen for consideration because they are representative of a range of physical and chemical behaviours and because of their importance in previous assessments. |
| Societal Assumptions: | Agricultural community, adopting modern practices (machinery and methods) for cultivation and animal husbandry. The resources available to the community are such that it is capable of producing locally a high proportion of the total diet of most foodstuffs. |
| Time Frame: | Up to 1 million years. |

It is recognised that a combination of multiple lines of reasoning, potentially involving different levels and types of detail and/or complexity, may be necessary in order to build confidence in an overall performance assessment. Hence, it is not necessarily the case that a single biosphere system description and related model will be sufficient, by themselves, to address fully the purpose of a particular assessment. Nevertheless, a preliminary list of potential assessment purposes can be identified, as an indication of the sort of roles for which it is thought that the prospective model might be useful. Thus, for example, a biosphere indicator developed according to the requirements listed above could have multiple purposes, as part of the approach aimed at meeting one or more of the following:

Purpose: Guide Research Priorities (Geosphere, Near Field and Engineered System).
Proof of Concept.
Regulator/Scientific Confidence.
Guide to Site Selection.

In what follows, each component of the assumed assessment context is considered in turn in order to discuss its potential implications for the development of ERB2A.

### C3.1.1. Assessment purpose

The main value of identifying various 'candidate' assessment purposes in advance of development of the Example is to highlight potentially relevant assessment objectives that could, if required, provide a reference point for selection or screening decisions. Regardless of this, however, it is important that the outcome of the exercise should be reviewed to evaluate the experience gained from development of ERB2A, and its relevance to these (and other) potential assessment purposes. This is to be done in a final section of the ERB2A report as part of a general discussion of the potential practical applicability of the final result.

The essential role of a biosphere model in radioactive waste disposal assessment is to provide a mechanism for estimating the radiological significance of potential future discharges of radionuclides. One incentive for using a relatively simple approach to biosphere assessment is to identify key differentiating factors in system performance, such as the design and/or representation of engineered barriers, or the geological host formation. In such circumstances, the precise value of the assessment endpoint is not so much a concern as the capability to distinguish between alternatives based on an adequate characterisation of radiological significance. Such a role for the biosphere model would be consistent with contributing to studies aimed at demonstrating proof of concept, identifying geosphere research priorities, or guiding site selection. A simplified approach is also potentially of value in applications where the main emphasis is to compare the relative performance of different engineered and natural barriers.

The range of candidate purposes described above is the same as that previously assumed in the development of the simple drinking water well, ERB1. It is anticipated, however, that by addressing a wider range of potential transfer and exposure pathways there is likely to be a comparatively higher level of assurance in relation to the calculated radiological impact.

### C3.1.2. Assessment endpoints

Different radionuclides are associated with distinct radiological hazards per unit activity. Guidance in respect to research priorities and site selection cannot therefore necessarily be provided on the basis of activity release rates (whether from the repository or geosphere) alone. There is a need to consider the potential behaviour of radionuclides and potential radiation exposures in sufficient detail to reflect the varying levels of radiological harm they could cause.

Most radiation protection standards incorporate limits on individual effective dose and, for simplicity, consideration has therefore been restricted here to the calculation of annual individual effective dose. It is important to recognise, however, that 'dose' values obtained using biosphere assessment models of the type being developed here can never be formally validated and should therefore be interpreted only as indicators of potential radiological impact, conditional on the various assumptions and hypotheses that underlie the assessment.

No age group (for the exposed individual) is specified, nor are the temporal and spatial domains over which the calculated annual dose is expected to be averaged. This is understood to reflect the status of current guidance in many countries relating to the demonstration of compliance with regulatory objectives for solid radioactive waste disposal. However, it is recognised that specific requirements could, if desired, be imposed via regulatory guidance. Detailed specification of the exposed individual is addressed under 'Exposure Group Definition' (below).

### C3.1.3. Assessment philosophy

The assessment philosophy provides a broad indication of how it is presumed that irreducible uncertainties should be addressed through basic assessment assumptions and hypotheses. As far as components of the assessment model other than the definition of the critical group are concerned, the assumption is that an 'equitable' assessment philosophy will be adopted. This is taken to imply that parameter value selection for the representation of contaminant transfer pathways in the biosphere model should be based on the assumption of realistic, rather than extreme values. More generally, equitable means based on a standard of protection relating to more normal or realistic circumstances, hence use normal or realistic assumptions.

By contrast, it is expected that the identification and description of potentially relevant pathways of radiation exposure will involve a more cautious approach. A cautious philosophy will tend to result in the use of generally conservative assumptions in order to ensure that, within the overall constraints imposed on the assessment, the results are unlikely to underestimate the corresponding dose that would arise for the release and exposure mechanisms considered. For example, whereas a contaminated well may be just one of several possible sources of water available to a community, a cautious approach to description of the hypothetical critical group dictates that calculations need be undertaken for those individuals for whom the well is the primary source of drinking water.

Nevertheless, adoption of a 'cautious' assessment philosophy within a particular assessment context cannot by itself guarantee that the assessment provides an upper bound estimate of the maximum potential exposure. For ERB2A the adoption of an agricultural biosphere does not necessarily result in the highest estimates of radiation exposure associated with the potential use of well water. This could be tested by exploration of, and comparison with, other potential uses of the contaminated water resource.

### C3.1.4. Repository type

Specific details of the type of repository under consideration are not usually directly relevant to the biosphere part of a performance assessment. However, restricting consideration to a deep repository for long-lived solid radioactive waste is generally consistent with the assumption of a constant release at the peak value to the biosphere over a time period sufficiently long enough for steady state to be achieved in a constant biosphere.

### C3.1.5. Site context

Some aspects of the site context will have a bearing both on the development of this Example Reference Biosphere and its ultimate applicability. For example, ERB2A will clearly be less relevant to situations where either geography or climate make the exploitation of wells to support agricultural water use unlikely. Moreover, because no specific assumptions (other than an inland location) are identified in the assessment context, it could be of some interest to explore the implications of a number of variant cases, based on alternative hypotheses regarding local climate and topography. These, in turn, would influence assumptions made in respect of farming and irrigation practice, how the water is used and how much is required. Such considerations need to be addressed as part of the process of biosphere system identification and description.

As a matter of practicality, the assumed location of any well needs to be such that the contaminated aquifer is at a reasonably accessible depth, based on the presumed habits and technology of the inhabitants of the local region. As a general rule, information concerning the assumed depth and location of the well would tend to be verifiable for any application to a specific site, i.e. capable of being shown to be consistent with current potential or actual practice.

### C3.1.6. Geosphere/biosphere interface

ERB2A is based on a simple assumption regarding the mode of contaminant release into the biosphere, i.e. the well abstraction of contaminated water, as in ERB1A. It is therefore implicitly assumed that all calculations (e.g. flow and transport effects, dilution arising as a result of pumping and other changes within the well itself) that may be required to determine concentrations of radionuclides in water delivered at the well head are supplied externally to the biosphere calculation. In any application of ERB2A, however, it would be necessary to co-ordinate geosphere and biosphere modelling activities to ensure that assumptions regarding abstraction rates and aquifer capacity in the geosphere model were consistent with corresponding assumptions (e.g. total water demand) in the biosphere model.

A more complex geosphere-biosphere interface, again with an agricultural biosphere, is addressed in ERB2B.

### C3.1.7. Source term

The concentration of each radionuclide in well water is assumed to be constant over the time frame of the assessment and within each year. Hence the results of the biosphere calculations will provide 'conversion factors' for annual individual effective dose per unit concentration in water at the well head. Radioactive progeny with relatively short half-lives can be assumed to be in secular equilibrium with their parents. The definition of short half-life will depend on rates of change in the system under consideration, and cannot be defined in advance.

In the overall performance assessment context, the assumption of an 'indefinite' release would be unrealistic, since it effectively implies that the source of radionuclides is unlimited. However, from a practical standpoint, the time taken for radionuclides to reach steady state concentration in the biosphere will generally be less than the duration of any 'peak' in the release rate from the geosphere. From the perspective of the biosphere assessment, therefore, this component of the assessment context is consistent with the presumption of no biosphere change.

It is not considered practicable to assume the same long list of radionuclides for ERB2 as was previously considered in ERB1. In particular, the need to evaluate multiple contaminant transport and exposure pathways is expected to place significant demands on data collection and analysis. Nb-94, Tc-99, I-129 and Np-237 are representative of a range of different physical, chemical and biological behaviours. They also illustrate the full range of potentially relevant exposure modes of significance, e.g. Nb-94, external irradiation; Tc-99 and I-129 accumulation in the foodchain; and Np-237, inhalation of suspended dust. In addition, these radionuclides that have been identified as of potential radiological significance in past assessments, e.g. (EPRI, 1996; Aguero, 2000). Special consideration could be given to C-14 because of its particular role in biospheric processes; ANDRA (1999). C-14 is not considered further in this Example. Other potentially special radionuclides include Cl-36 and Se-79 because of their very high potential for root uptake.

#### C3.1.8. Societal assumptions

In order to avoid endless speculation regarding the technology, physiology and socio-economic structures of future communities, the primary assumption is made that the activities and characteristics of the population exploiting the well water are similar to those of present-day communities. This is intended to be consistent with the IAEA’s general principle of ensuring that predicted impacts on the health of future generations will not be greater that the relevant levels of impact that are acceptable today (IAEA, 1995).

The assumed assessment context dictates consideration of an agricultural community. Moreover, the assumption that a high proportion of consumption can be delivered by locally-produced foodstuffs is consistent with the adoption of a ‘cautious’ approach to definition of the hypothetical critical group. Consideration of the range of potential exposure pathways involved in the production and consumption of these foodstuffs implies a need to take into account various aspects of the migration and accumulation of radionuclides as well as the specific aspects of accumulation in the foodchain. The multiple pathways associated with this biosphere system represent a valid basis for comparison with the single drinking water assumed in ERB1A. Note that drinking water only would not address the endpoints of interest consistent with the purpose.

#### C3.1.9. Time frame

The aim is that this Example should be relevant to potential releases that might occur within such a time frame. It is not intended to imply that the biosphere will remain constant for a period of one million years; only that the results should be applicable to any geosphere release within that period.

### C3.2. BIOSPHERE SYSTEM IDENTIFICATON AND JUSTIFICATION FOR ERB2A

The biosphere system is not fully defined by the assessment context (e.g. by legislation or guidance) and so the relevant components of the biosphere system must be identified and justified. The identification and justification process is based on the classification scheme presented in Part B.

One of the more important factors determining the identification of components of the biosphere system is the assumed degree of control or management by the local human community. There is no explicit guidance on this matter in the assessment context for

ERB2A. However, given that a present day agricultural community is to be assumed (societal context) and that the primary route of contamination of the biosphere system is via the use of well water (geosphere/biosphere interface), it is appropriate to focus attention on a highly controlled ecosystem.

This decision does not deny any possible interest in the potential radiological implications of secondary contamination of natural and/or seminatural ecosystems. Indeed, it would be relevant – particularly in the context of demonstrating formal compliance with radiation exposure criteria – to consider whether realistic uses of well water by an agricultural community (e.g. irrigation of crops, watering of livestock and domestic uses) might give rise to comparatively significant secondary transfer and exposure pathways. However, since a primary role of the Example is to illustrate the potential significance of multiple pathways compared with drinking water only, the introduction of even more potential exposure pathways in ERB2A is unnecessary. This might also be true if, as anticipated in the assessment context, the purpose of the biosphere assessment were simply to guide the comparison of alternative sites and disposal concepts. However, this would only be the case for release to agriculturally productive systems. It is also relevant to note that a more complex geosphere-biosphere interface, potentially leading to direct contamination of surface water bodies and wetland, as well as agricultural ecosystems, is addressed in ERB2B (Section C4).

### C3.2.1. Climate (Table CI)[12]

In principle, ERB2A could be explored in a number of constant climate variants, each consistent with the underlying assumption that agricultural use if made of well water (e.g. for irrigation) at an inland site. However, it is noted that climate class ZBVII represents (according the scheme of Walter (1984)) the “temperate” climate class with the highest requirement for irrigation on the basis of its characteristic low rainfall and high summer temperatures.

### C3.2.2. Topography (Table TI) and geographical extent

The following topographical characteristics (selected from Table TI) of the biosphere system in the region exploited by the local community can be identified, consistent with the assessment context:

- Geographical context: *inland* – as specified;
- Altitude: *lowland* – a site is more likely to have a contaminated regional aquifer at accessible depth in a lowland location;
- Landform: *plain* – this is the alternative most consistent with the use of irrigation water for agricultural purposes;
- Localised erosion: *limited localised erosion* – most consistent with the choice of the land for agricultural purposes and the absence of significant surface water courses (as alternative water sources).

It is recognised that alternative topographic characteristics might equally well have been identified. For example, a subdued landform with gentle slopes would also be broadly consistent with the assumption of agriculture in an inland lowland, region. It may therefore be

[12] Table references are to Annex BI of Part B.

of interest to consider the extent to which the Reference Biosphere derived for a specified assessment context is sensitive to alternative assumptions such as this or whether, within defined limits, this component of the biosphere system is only of secondary importance.

### C3.2.3. Human community (Table HI)

The assessment context implies that consideration should be given to localised, diversified systems of food production, rather than commercial, or industrialised, farming practice. This has the effect of introducing a need to consider a diversity of pathways. This points towards the identification of a small-scale trading community, which imports materials in order to sustain modern farming practices, but is capable of providing a major proportion of the dietary requirements of at least some of its inhabitants. This is identified in Table HI as a small farming community living off local produce.

The level of environmental control by such a community is relatively high. Land is used primarily used for crop production and animal husbandry/grazing. For the ERB2A assessment context, woodland management is excluded on the basis that irrigation of such woodland is practised only on a commercial forestry basis. Aquaculture is excluded since it is not considered to be a prevalent agricultural practice in present-day temperate regions where a well is the only source of water. Zero-land and climate-controlled farming is excluded since it is not compatible with the assumption of present-day, small-scale trading in temperate regions. Urban/suburban, industry and other large-scale trading activities are excluded by the assessment context requirement to consider an agrarian society.

### C3.2.4. Near-surface lithostratigraphy (Tables GI, SI and RTI)

The underlying rock type is only of secondary relevance to ERB2A, since the way in which the geosphere/biosphere interface is described means that there is no need describe the regional aquifer as part of the biosphere system. Any of the proposed geological categories in Table GI could in principle, be selected. However, because the assessment context states that an aquifer is present and, for many regions of the world, aquifers are more likely to be exploited in sedimentary rather than in metamorphic or igneous rocks, sedimentary rock has been identified as being most consistent with the assessment context.

Identification of the predominant soil type as a chernozem is generally consistent with the assumed climate (Table RTI) and geographical context. The productivity of such soils is also consistent with the agrarian basis of the assessment context.

### C3.2.5. Water bodies (Table WI)

Natural surface water bodies are excluded from the biosphere system on the basis that they are not required by the assessment context. Moreover, it is considered desirable to avoid unnecessary complexity in development of the biosphere system description. Secondary contamination pathways associated with natural surface water bodies might occur in principle but it is not necessarily helpful to incorporate such pathways in ERB2A. Indeed, it will be generally more cautious to assume that all water resources are derived from the well, rather than from local surface waters. Direct contamination of surface water bodies is to be considered in ERB2B.

Clearly, a well needs to be identified as part of the biosphere system, since this is a fundamental element of the assessment context. In addition, small-scale, artificial surface water bodies, such as water cisterns or ponds/reservoirs for animal watering, might perhaps be anticipated as part of a coherent water distribution system. However, other, larger-scale, artificial water bodies (canals, reservoirs, etc) can readily be excluded for the same arguments used above to exclude natural surface water bodies, as well as being inconsistent with the assumed human community. While the aquifer has to be large enough to support the water needs of the community, it does not have to come from just one well.

The variably saturated zone is identified as being a relevant component of the biosphere system, because of the need to consider the consequences of irrigation of soils by contaminated groundwater. The saturated zone is also considered to be relevant, but only in so far as it represents a "sink" for mass balance purposes. Consequently, this component of the system does not require more detailed characterisation. Ice sheets are excluded on the basis of the assumed geographical context and the local climate.

#### C3.2.6. Biota (Table BI)

Table BI provides an initial classification of terrestrial and aquatic ecosystems as a function of the assumed level of system management. Consistent with the underlying assessment context, it is possible to identify a managed, cultivated ecosystem as being consistent with the overall assessment context.

All surface water bodies (other than the well and water storage and distribution system) have been excluded from the identified biosphere system. The only managed aquatic ecosystems that are relevant to describing biotic communities are therefore those associated with man-made reservoirs. In addition, given the assessment context and the various arguments developed above, all managed terrestrial ecosystems can be excluded with the exception of:

- managed and improved grasslands (rough grassland is excluded since irrigation of such land is considered to be unlikely);
- field crops/cultivated land, and
- tree crops (non-commercial).

#### C3.2.7. Biosphere system change

The assessment context specifies that biosphere system change need not be considered for ERB2A. A constant biosphere system based on the different components identified above can therefore be assumed.

### C3.3. BIOSPHERE SYSTEM DESCRIPTION FOR ERB2A

#### C3.3.1. Screening of system characteristics

The first step of the biosphere description procedure is to identify those characteristics and properties of each component of the biosphere system identified above that are relevant to providing an assessment-oriented description of the system. This is achieved by working through a checklist of common general characteristics, descriptive of potentially relevant features for each component, and selecting specific items for their relevance to the overall assessment objective according to the assessment context and any additional assumptions invoked in the preceding system identification.

The following discussion summarises the screening arguments considered in respect of the different components types (Type II Tables from Annex BI of Part B).

*C3.3.1.1. Climate characteristics*

Consideration of climate characteristics contributes to providing a coherent overall description of the biosphere system, especially in so far as precipitation is an important contribution to the availability and quality of local surface resources (and hence demands on aquifer use). Other components of climate are important in determining the growth regime of plants, animal husbandry practices, water demand etc. Table C6 summarises the screening arguments that have been deployed in respect of the climate characteristics of the biosphere system.

The assessment context for ERB2A specifies no biosphere change. Nevertheless, relatively short-term variability may be relevant to the radiological assessment, in so far as the use of water will be influenced by climate fluctuations over diurnal and seasonal timescales. Interannual and decadal variabilities have limited relevance to the determination of lifetime average exposures and it is assumed that they will be addressed through the selection of appropriate annual-average parameter values based on measurements over decades.

The geographical extent of the biosphere system is restricted to the region within which agricultural practices involving the use of well water are carried out by the local community. There is unlikely to be any significant spatial variability in climate over the domain of the biosphere system, particularly as it is assumed that the site is situated on a plain. This factor can therefore be considered irrelevant to the system description.

TABLE C6. CLIMATE CHARACTERISTICS

| Component Type | Characteristic | Relevant? | Comments |
|---|---|---|---|
| Climate characteristics (Table CII) | Temperature | Y | Temperature and precipitation determine basic productivity and need for irrigation. |
| | Precipitation | Y | Pressure not relevant (no gas release). |
| | Pressure | N | Wind speed ruled out on basis of low importance |
| | Wind speed/direction | N | (can determine evapotranspiration without it). |
| | Solar radiation | N | Effects covered in temperature. |
| Temporal variability of climate (Table CII) | Diurnal | Y | Probably not represented explicitly in models. |
| | Seasonal | Y | Seasonal because it determines the growing season and need for irrigation. |
| | Interannual | N | Longer term variations ruled out on basis of low |
| | Decadal | N | relevance to lifetime average exposure. |
| Spatial variability of climate (Table CII) | Latitude | N | Spatial extent too small for climatic variation. |
| | Longitude | N | No significant variation in a plains area. |
| | Altitude | N | |
| | Aspect | N | Aspect not relevant for a plains area. |

*C3.3.1.2. Geology, soil and topography characteristics*

As the geosphere/biosphere interface is restricted to abstraction of water via a well, the only function of the saturated zone is to act as a sink for percolating water. Detailed characteristics of the underlying geology are therefore largely irrelevant, except in so far as they influence the properties of the soil and variably saturated zone. Soil characteristics are relevant to providing a description of the structure and composition of the substrate within which crops are grown. Table C7 summarises the screening arguments deployed in respect of these aspects of the biosphere system.

The topography does not have a major influence on the overall system description, although its characteristics may be relevant to considerations such as the description of field drainage.

Table C7 summarises the screening arguments deployed in respect of this component of the biosphere system description.

*C3.3.1.3. Hydrology characteristics*

Identified water bodies present within the biosphere system include a well, variably saturated zone and saturated zone. There is also the possibility of including consideration of a small reservoir, or pond, to distribute water for irrigation and animal watering. Table C8 summarises the screening arguments deployed in respect of these aspects of the biosphere system.

TABLE C7. GEOLOGY SOIL AND TOPOGRAPHY CHARACTERISTICS

| Principal Component Type | Characteristic | Relevant? | Comments |
|---|---|---|---|
| Consolidated/ Solid Geology (Table GII) | Lithostratigraphy | Y | Only relevant insofar as it affects the past development and present type of soil. |
| | Fracture systems | Y | |
| | Degree of weathering | Y | |
| | Erodability | Y | |
| | Mineralogy | Y | |
| Unconsolidated/ Drift Geology (Table GII) | Lithostratigraphy | Y | Only relevant insofar as it affects the type of soil and as a host for the variably saturated zone. An unspecified transmissivity is required to allow sufficient water movement. |
| | Fracture systems | Y | |
| | Degree of weathering | Y | |
| | Erodability | Y | |
| | Deposition rates | Y | |
| | Mineralogy | Y | |
| Soil (Table SII) | Stratification (e.g. soil horizons) | Y | ≥60 cm, organic rich, A-horizon. Sub soil consistent with sedimentary geology. |
| | Composition (organic content, mineralogy) | Y | ) Apart from breaking up any possible iron pan by ) ploughing and cultivation effects on humus content, ) the composition and texture of the cultivated soil ) will be largely those of unmodified chernozems. |
| | Texture | Y | |
| | Areal variation | Y | Potentially relevant to extensive agricultural region. |
| Topography (Table TII) | Altitude | Y | Low enough to permit agriculture. |
| | Slope | Y | 0-5% according to plain topography. |
| | Erodability | N | Limited significance in region of low relief with no surface water courses. Assessment context requires that biosphere system should be constant. |
| | Deposition Rate | N | |

It can be inferred from the assessment context that technological development is sufficient to allow for abstraction of water to take place. The actual level of technology required would depend on the specific situation in which abstraction takes place. Simple excavation into a shallow aquifer requires less technology than pumping from a borehole drilled into a deep, relatively impermeable, formation.

Although not strictly part of the system description for this Example, consideration of local community structures may be implicit in other basic assumptions adopted regarding the biosphere system and/or exposure groups. For example, a small, remote (or even temporary) community may be less likely to invoke complex water storage and distribution systems prior to use, whereas industrialised abstraction for a larger population might involve more sophisticated technologies.

TABLE C8. HYDROLOGY CHARACTERISTICS

| Biosphere System Component | Characteristic | Relevant? | Comments |
|---|---|---|---|
| Well (Table WII) | Geometry | N | Excluded by assessment context |
| | Flow Rate | N | Excluded by assessment context |
| | Suspended Sediment | Y | Composition and load, pH, Eh |
| | Freeze/Thaw Phenomena | N | |
| | Hydrochemistry | Y | |
| Variably Saturated Zone (Table WII) | Geometry | | |
| | – Level | Y | Seasonal variation |
| | – Basal | N | Not relevant to irrigation |
| | Flow Rate | N | Not relevant given source term in assessment context |
| | Freeze/Thaw Phenomena | Y | Influence of snowpack development |
| | – Ground Freezing | N | Not relevant |
| | – Water Body Freezing | Y | Potential influence on sorption |
| | Hydrochemistry | | |
| Saturated Zone (Table WII) | Geometry | N | ) Only role of saturated zone within |
| | Flow Rate | N | ) conceptualised system is as a sink for |
| | Freeze/Thaw Phenomena | N | ) infiltrating water. Characteristics are |
| | Hydrochemistry | N | ) irrelevant to assessment context. |

Although consideration of population size does not necessarily influence the biosphere system description, it may be important in applying and interpreting the results. For example, the size should be consistent with the underlying geosphere characteristics, in so far as radionuclide concentrations in well water are assumed to be unaffected by withdrawal rates, or variations in withdrawal rates. It might also be inferred from the assessment context that, if water abstraction is to be sustainable over an indefinite period, population size should be compatible with the capacity of the aquifer. Moreover, the overall community context (combined with local lithostratigraphy) may affect the type of well that is constructed, and hence the potential (as well as the realised) abstraction rates in any given situation. Predication of a particular abstraction rate (necessary to guide the geosphere calculations) will constrain the type of well that can be used.

Based on the above information, Tables C9 and C10 identify and describe the biosphere system for ERB2A.

TABLE C9. BIOSPHERE SYSTEM IDENTIFICATION FOR ERB2A

| System Component | Classification | Reasons |
|---|---|---|
| Geographical Extent | Minimum area sufficient to meet the purpose of the assessment, consistent with the assumed use of well water. Precise definition depends on assumed size of the exposure group. | |
| Climate | ZBVII, possibly ZB VI. | Both are Temperate, as required by assessment context. ZB VII has higher need for irrigation. |
| Geographical Context and Topography | Inland<br>Lowland<br>Plains (but could be almost any subdued landform)<br>Limited localised erosion | From context<br>A contaminated aquifer at accessible depth in an agricultural setting is more likely to be associated with a lowland location.<br>Consistent with requirement for irrigation and use of land for agricultural purposes. |
| Human Activities | Small-scale trading community<br>Agricultural land use with production of animal products and crops for human and animal consumption. | Intensive production of a variety of products consistent with assessment context assumption of non-commercial/non-industrial agricultural practice.<br>No glasshouse horticulture or gardening because these are largely covered by consideration of other crop production. No production of non-edible crops (e.g. tobacco) on basis of low consequence and need for simplicity |
| Geology | Sedimentary (but not a critical assumption and could be any of the other classes listed) | Consistent with the presence of an aquifer, as required by the assessment context. Unconsolidated sediments (e.g. glacial drift) not specifically identified. |
| Water Bodies | Wells<br>Variably saturated zone<br>Saturated zone as a fixed source and sink | No open water bodies – for simplicity. These are considered of secondary importance in any case for a release via use of well water. |
| Soils | Chernozem (primary requirement is consistency with assumed climate, geographical context and land use) | Soil type should provide a reasonably robust estimate of potential transfer pathways (i.e. with respect to bioavailablity and sorption) |
| Ecology | Managed, cultivated land<br>– Managed and improved grasslands<br>– Field crops, cultivated land<br>– Tree crops (non-commercial) | All other managed terrestrial ecosystems can be excluded by reference to the assessment context and assumed human activities, with the exception of those identified here. |

TABLE C10. BIOSPHERE SYSTEM DESCRIPTION FOR ERB2A

| Biosphere System Component | Descriptive Class | In? | Reason |
|---|---|---|---|
| Climate characteristics | Temperature | Y | ) Temperature and precipitation determine basic |
| | Precipitation | Y | ) productivity and need for irrigation. |
| | Pressure | N | Pressure not relevant. |
| | Wind speed/direction | N | Wind speed ruled out on basis of low consequence |
| | Solar radiation | N | (can determine evapotranspiration without it). |
| Temporal variability of climate | Diurnal | Y | Probably not represented explicitly in models |
| | Seasonal | Y | Seasonal because it determines the growing season and need for irrigation. |
| | Interannual | N | ) Longer term variations ruled out on basis of low |
| | Decadal | N | ) relevance to lifetime average exposure. |
| Spatial variability of climate | Latitude | N | Spatial extent too small for climatic variation. |
| | Longitude | N | |
| | Altitude | N | No significant variation in a plains area. |
| | Aspect | N | Aspect not relevant for a plains area. |
| Consolidated/ Solid Geology | Lithostratigraphy | Y | Only relevant insofar as it affects the type of soil. |
| | Fracture systems | Y | |
| | Degree of weathering | Y | |
| | Erodability | Y | |
| | Deposition rates | Y | |
| | Mineralogy | Y | |
| Unconsolidated/ Drift Geology | Lithostratigraphy | Y | Only relevant insofar as they affect the type of soil and as a host for the variably saturated zone. An unspecified permeability is required to allow water movement. |
| | Fracture systems | Y | |
| | Degree of weathering | Y | |
| | Erodability | Y | |
| | Deposition rates | Y | |
| | Mineralogy | Y | |
| Soil | Stratification (e.g. soil horizons) | Y | Chernozems of order of 30 cm thickness organic rich<br>Assume entire root zone is in contaminated zone<br>Sub soil consistent with sedimentary geology |
| | Composition (organic content, mineralogy) | Y | ) Apart from breaking up any possible iron pan by<br>) ploughing and cultivation effects on humus content, |
| | Texture | Y | ) the composition and texture of the soil will be<br>) largely those of unmodified chernozems and the<br>) same as cultivated chernozems. |
| | Areal variation | Y | Some areal variation that can be explored using a range of parameter values. |
| Topography | No Table TII | Y | Methodology needs some modification here but is adequate for this Example (Note that Table TII was developed subsequent to ERB2A) |
| | Chemical changes to the environment | N | Have described environment (e.g. soil) so we do not need to consider chemical and physical changes. |
| | Physical changes to the environment including construction of ponds, demolition of buildings | N | Limited effect if small changes, and large changes not included in a constant biosphere. |
| Human Activities | Land reclamation<br>*Recycling and mixing of bulk materials* | N | Time-dependent event |
| | – Ploughing | Y | |
| | – Well | Y | Well water is sole source |
| | – Other water | N | |
| | – Irrigation | Y | |

TABLE C10. BIOSPHERE SYSTEM DESCRIPTION FOR ERB2A (CONTINUED)

| Biosphere System Component | Descriptive Class | In? | Reason |
|---|---|---|---|
| Human Activities (Continued) | *Recycling of bulk solid materials* | | |
| | – Artificial mixing of water bodies | N | Well water is sole source. |
| | – Dredging | N | Infrequent activity, low consequence. |
| | – Controlled ventilation | Y | Incorporated in air exchange rates. |
| | *Redistribution of trace materials* | | |
| | – Water treatment | N | Assessment Context. |
| | – Waste water treatment | Y | As soil improvement. |
| | –Air filtration | Y | Passive effects in enclosed spaces. |
| | – Food processing | Y | Can decrease or increase concentrations. |
| Water Bodies | Sea level | N | Not relevant to wells only. |
| | Basal characteristics | Y | Only if we define a tank or pond for animal watering. |
| | Suspended sediments | Y | |
| | *Freeze thaw phenomena* | | |
| | – Seasonal | Y | |
| | – Long term | N | No long-term freezing in this climate. |
| | – Snow pack development | Y | |
| | – Water body freezing | N | Pond wouldn't be allowed to freeze. |
| | *Ice sheet* | N | Inconsistent with assessment context. |
| | *Hydrochemistry* | | |
| | – Major ions | Y | |
| | – Minor ions | Y | |
| | – Organic compounds | Y | |
| | – Colloids | Y | |
| | – Sorption | Y | |
| | – Precipitation/dissolution | Y | |
| | – Mineralisation | Y | |
| | – pH and Eh | Y | |
| Water Balance | Precipitation | Y | On land. |
| | Irrigation (new item) | Y | |
| | Evaporation | Y | On land. |
| | Transpiration | Y | |
| Land surface f | Infiltration | Y | |
| | Runoff | N | Cautious to ignore – plain topography |
| | Ground water discharge | N | Assessment context |
| | Porous medium | Y | |
| | Fracture flow | N | No, this applies to rocks only |
| | Macropore flow | Y | |
| Water bodies f | Surface water flows | N | No, only need flow through soil - above |
| Water bodies second column | Subsurface water flows | N | No – if applied to water bodies only (which is what the table implies) |
| Land surface b | Interception | N | Incorporated in evaporation and transpiration |
| | Leaf drip | N | Incorporated in evaporation and transpiration |
| | Stemflow | N | Incorporated in evaporation and transpiration |
| | Interflow (throughflow) = storage | Y | |

## C3.4. EXPOSURE GROUP DEFINITION FOR ERB2A

### C3.4.1. Review of exposure modes and biosphere system components

Consideration of the potentially contaminated media identified in the ERB2A system description and of exposure modes in a generic agricultural context in a temperate climate gives rise to the example exposure routes documented in Table C11 (the ERB2A specific version of Table HIIb in Annex BI of Part B).

TABLE C11. EXPOSURE MODES, EXPOSURE ROUTES, EXAMPLES OF TYPICAL ACTIVITIES ASSOCIATED WITH THOSE ROUTES AND PARAMETERS CHARACTERISING THE ACTIVITIES

| Source/ medium | Exposure mode | Example exposure route | Examples of typical activities | Assumed parameters |
|---|---|---|---|---|
| Soil | inhalation | *gaseous release to air* | *outdoor activities*, indoor activities | A, B, E |
| | | *resuspension of soil particulates* | *ploughing, walking, misc. outdoor activities, indoor exposure resulting from soil brought inside* | A, B, E |
| | ingestion | *incidental soil ingestion* | *gardening, fresh fruit and veg. consumption, recreational activities, occupational activities* | A, B, H |
| | | deliberate soil ingestion | soil pica | B, H |
| | external | *external radiation exposure* | *activities over/near contaminated soil, including dermal contact*, living in buildings made of contaminated soil | A, C, F, G |
| Water | inhalation | *spray/aerosols/volatiles* | *spray (irrigation,* surface water*), recreation, domestic (showering, sauna, cooking)*, recreation/fishing | A, B, E |
| | ingestion | *deliberate water intake* | *drinking, as a part of diet in other foods (cooking)* | B |
| | | incidental water intake | during swimming, bathing, showering | A, B |
| | external | submersion in water | bathing, swimming | A, C, F, G |
| | | *external exposure from water bodies* | *working near bulk water* (*storage tanks,* filtration systems), recreational activities near water bodies | A C, F, G |
| | dermal absorption | submersion in water | farming activities, interception of spray irrigation, swimming, bathing | A, B |
| Sediments | inhalation | gaseous release to air | outdoor activities on exposed sediments, and sediments transferred to soil by dredging | A, B, E |
| | | (re)suspension of dried sediments | dredging, maintenance of water distribution system, farming, activities on shorelines and near perennial lakes | A, B, E |
| | | spray including suspended sediments | irrigation spray, showering | A, B |
| | ingestion | incidental ingestion | dried/exposed sediments as deposits on food, or fingers, suspended sediment with water | B |
| | | deliberate ingestion | sediment pica (dried exposed sediments only) | B, H |
| | external | γ-irradiation from bulk sediments | activities (recreational and occupational) near exposed sediments, dried sediments, swimming, bathing | A, C, F, G |
| Air | inhalation | breathing | all activities (indoor, outdoor, including sleeping) | A, B |
| | ingestion | particulate deposition on surfaces/foodstuffs | eating, recreational activities | B, D, H |
| | external | submersion dose | γ-exposure from airborne concentrations (all types of activity) | A, C, F, G |
| Plants and plant products | inhalation | *particulates from combustion, from plant processing* | *burning of plant material* (wood, *stubble*, specific crops, e.g.., tobacco), milling | A, B, E |
| | ingestion | *food consumption* | *eating, drinking plant material as part of the diet, root veg. , green veg, cereals, fruit, etc.* | B |
| | external | *γ-exposure from plants and plant products* | *Working/ recreation in fields, storage of plants, wearing cloths derived from plants*, building materials | A, C, F, G |
| Animals and animal products | inhalation | inhalation of animal derived particulates | derived from domestic activities (cooking), occupational activities (incineration, butchery, tanning) | A, B, E |
| | ingestion | *food consumption* | *animal products consumed include meat, milk, offal, eggs, dairy products, other products (e.g., gelatin)* | B |
| | external | *γ-exposure from animals and animal products* | *animal husbandry, processing/storage of animal products and materials* | A, C, F, G |

Legend:

| | | | |
|---|---|---|---|
| A - | Exposure duration (hours $a^{-1}$) | B - | Rate of intake (kg $a^{-1}$) |
| C - | Shielding of source (yes/no, shielding factor) | D - | Deposition rate (kg $m^{-2}$ $a^{-1}$) |
| E - | Resuspension/release rate [(kg soil) ($m^3$ air)$^{-1}$, $m^{-1}$, kg $hour^{-1}$, etc.] | F - | Source geometry (infinite plane, line, sphere, semi-infinite cloud, etc.) |
| G - | Relation to source (distance, orientation – above, beside, below, immersed, etc.) | H - | Age specific information relevant |

Taken in turn, the entries in Table C11 build up a description of exposure routes relevant to the ERB2A biosphere, related to contamination in environmental media:

*C3.4.1.1. Soil*

Inhalation pathways may be related to contamination in soil in two ways:

(1) as a result of gaseous release to air; and

(2) by the (re)suspension of soil particles into the atmosphere.

Both mechanisms give rise to radionuclide content in inhaled air. Relevant considerations are the duration of the exposure (i.e. time at relevant location), the rate of intake (breathing rate and concentration at location) and the rate of release or resuspension from the soil at the relevant time and place. The human activities as regards exposure should be considered consistently with the assumptions for these parameters. Indoor activities would not lead to doses by this route in ERB2A because soil only becomes contaminated by irrigation and this would not apply to domestic soils under housing.

Soil can be directly ingested by a number of potential mechanisms. In the context of ERB2A it is relevant to consider the soil contamination of fresh produce (fruit and vegetables). Recreational activities could also contribute – for example certain sports involve close encounters with mud and soil. Simon (1998) also notes the correlation between soil intake and occupational activities involving high dust loadings. Children are also likely to have a greater soil intake than adults and this feature may be of relevance and so age dependent characteristics of the exposed groups are relevant. This is in addition to duration and intake rate considerations.

Deliberate soil ingestion is also possible but this is considered extreme behaviour and so is ruled out of consideration.

External exposure from contaminated soil. All activities over or near contaminated soils are relevant and this implies that the duration at any given location is a necessary part of the dose calculation, as well as some idea as to the likely shielding affects of clothing, structures or vehicles – a farmer ploughing in an enclosed tractor cab would be shielded whereas a gardener digging the garden would not. The geometry of the source is therefore also relevant as well as the distance from the source to the exposed person.

Given present day construction practices it is unlikely that local surface soils would be used as building materials and so this potential pathway is not further pursued in ERB2A, see the Assessment Context.

*C3.4.1.2. Water*

Water bodies in the ERB2A system have a restricted scope. There are no rivers, lakes or swimming pools assumed and the only water is obtained from the well head via a water distribution system. This may involve storage tanks but these are not used for recreational purposes.

As with soils, water bodies can also act as a source of volatile radionuclides which can be inhaled. Evaporated water is unlikely to carry waterborne radionuclides but water droplets, with their radionuclide content intact, can play a role as aerosols and spray. A number of possible activities may be identified in the ERB2A system. Given the absence of other water bodies in the ERB2A system, spray irrigation is assumed as the means of irrigating agricultural crops and this provides one route.

Water may be ingested either deliberately or inadvertently. Deliberate ingestion includes water as a drink and as a component of other beverages. Deliberate intake may also arise with water as a component of other foods. These intakes can be subsumed in a single intake rate. Other activities, notably swimming and bathing may result in non-deliberate ingestion. The amount ingested during bathing and showering is likely to be very small compared to the dietary intake, and so is neglected here

Bulk water can potentially lead to external doses either by the immersion of the body in the body of liquid or as a distant source of external irradiation. Relevant parameters are duration, shielding, source geometry and source to target distance. In the context of ERB2A, this route is restricted to individuals located close to water storage facilities. Filtration systems are not included in the water distribution system.

Dermal absorption might take place during a number of activities and doses would require the duration of the exposure. However, this exposure mode is not likely to be significant (BIOMOVS II, 1996a).

*C3.4.1.3. Sediments*

As there are no natural water bodies in the system, bed and exposed sediments do not play a role in ERB2A.

*C3.4.1.4. Air*

As indicated in Table C11, the role of air in ERB2A is wholly subsumed into the pathways involving water and soils sediments. The only route not explicitly covered elsewhere concerns immersion of the body in a cloud of radioactive gas. For the radionuclides considered in ERB2A, this is not considered significant.

*C3.4.1.5. Plants and plant products*

Plant material may be converted to inhalable form by a variety of processes. Doses via inhalation require duration and amount of intake. In the context of ERB2A, the annual combustion of crop residues (stubble burning) is one option arising from burning contaminated plant material. Milling flour could also lead to airborne dust concentrations derived from plant material. It is not considered likely that pollen would contribute to the inhalation dose. Wood burning is not expect to play a role in ERB2A since the only trees in the system are fruit trees and, in the context of modern practices, it is not assumed that these are harvested as a source of fuel. The Assessment Context precludes commercial forestry for fuel.

Plant material forms a basis of the diet and a number of crops could be produced in the ERB2A biosphere. These may be used both for solid food and as a source of beverages. As such these routes are included in the exposure pathways relevant to the system. The consumption of each food type is required.

Just as soils may give rise to external exposures, accumulations of radionuclides in plant material (growing as well as harvested plants) may expose persons in the vicinity, again depending on duration, shielding factors, source geometry and location relative to the source. The Assessment Context precludes commercial forestry and so building materials derived from locally produced timber is excluded.

*C3.4.1.6. Animals and animal products*

Inhalation doses derived from concentrations in animals require the conversion of animal material into airborne particulates. A number of processes could be at work but they are regarded as having low impact on the composition of the atmosphere and are not considered further. Duration and amount of exposure are relevant but the limiting factor is likely to be the source term to atmosphere, which is likely to be small compared to other routes by which inhalation doses could arise.

A major element is radioactivity in consumed animal products, as listed in Table C11. Consumption rates are relevant.

Proximity to animals, especially livestock, in which activity has become concentrated could also give rise to external doses. Similarly processing and storage of animal materials and products may have a role to play. The four relevant parameters in this exposure route are duration, shielding factors, source geometry and location relative to the source.

### C3.4.2. Identification of relevant activities engaged in by exposure groups in ERB2A

It is helpful to extract the pathways relevant to ERB2A and to arrange them according to exposure mode, as illustrated in Table C12. The parameters associated with the pathways aid in the further sub-classification of the exposure routes so that whereas food consumption rates are all that determines food intake, duration at location is needed to characterise inhalation doses and duration and location relative to source is needed to determine external doses.

The requirement to consider durations implies that there is a corresponding requirement to determine the type of activity. One way of doing this is to sub-divide time spent as occupational, recreational, domestic and sleeping. This method was found to be useful in characterising exposure group behaviour.

The aim of identifying exposure group behaviour is not to model all aspects of possible behaviour. Rather, the requirement is to capture a sufficiently broad spectrum of behaviour, relevant to the context of the assessment, so that representative behaviour is included when exposure group characteristics are parameterised into the mathematical model.

This process identifies a broad range of relevant activities from which a number of a priori exposure groups can be distinguished. As always, if it can be established that some other aspect of behaviour would lead to significant exposure (taking into account that it may be mutually exclusive with other aspects of behaviour already identified) then it may be added. However, it is believed that the ensemble of exposure pathways described here is sufficiently broad that any additional behaviour may be subsumed into one or more of the existing pathways.

TABLE C12. ACTIVITIES IN ERB2A WHICH GIVE RISE TO THE EXPOSURE PATHWAYS

| | | |
|---|---|---|
| **Ingestion – consumption of contaminated materials** | | |
| – meat | – fruit | – water |
| – offal | – root vegetables | – soils (directly and indirectly) |
| – milk | – green vegetables | |
| – milk products | – cereals | |
| – eggs | | |
| **Inhalation – breathing contaminated air whilst engaged in:** | | |
| – **Occupational** | | |
| – plant burning – outdoors | | |
| – ploughing/digging irrigated land | | |
| – irrigating irrigated land | | |
| – general farm work near water storage | | |
| – general farm work on irrigated land | | |
| – plant processing and storage indoors | | |
| – animal husbandry, product processing and storage | | |
| – harvesting on irrigated land | | |
| – milking indoors | | |
| – manuring (indoors and outdoors) | | |
| – Recreational (Non-occupational) | | |
| – out-door activities on irrigated land | | |
| – outdoor digging (gardening) | | |
| – watering the garden | | |
| – **Domestic** | | |
| – general domestic activities (ambient dust levels) | | |
| – general domestic activities (elevated dust levels) | | |
| – domestic showering/bathing/sauna | | |
| – cooking | | |
| – domestic activities involving the use of water (car cleaning, etc.) | | |
| – **Sleeping** | | |
| **External – whilst in the vicinity of contaminated materials** | | |
| – **Occupational** | | |
| – general farm work on irrigated land (unshielded) | | |
| – general farm work on irrigated land (shielded) | | |
| – general farm work near water storage body | | |
| – plant processing & storage indoors | | |
| – animal husbandry and product processing (indoors) | | |
| – clothing | | |
| – general indoor – no external sources | | |
| – **Recreational** | | |
| – out door activities on irrigated land | | |
| – clothing | | |
| – Domestic | | |
| – general indoor activities – no external source | | |
| – proximity to stored plant and animal materials | | |
| – **Domestic – clothing** | | |
| – bathing/showering/sauna | | |
| – **Sleeping** | | |
| – sleeping under bedding | | |

### C3.4.3. Basis for the identification of exposure groups in ERB2A

Exposure groups of interest in the assessment combine characteristics so as to reasonably maximise group exposure. The exposure pathways and their activating behaviour need to be chosen in such a way as to combine exposures via different pathways so as to produce a total annual individual dose to members of the identified exposure group which may be taken to be reasonably representative of the highest doses to persons with those habits and lifestyles.

Combination of activities focuses on exposures by:

- intakes (ingestion and inhalation);
- location;
- activity; and
- duration.

Soils become contaminated by irrigation. Occupancy of soils can therefore lead to external doses. It has been noted that accumulations of activity in crops can lead to external doses if storage of plant material leads to high densities in barns and silos, etc. How can a maximised dose be calculated in this case? Should it be assumed that the member of the farming group has 100% residency of the soils, which happens to be near barns and other farm buildings used for storage? How may time spent in the domestic environment reasonably and consistently be included? All this implies that some sort of time-balance for potentially exposed members of identified groups should be considered.

Concerning foodstuffs, Robinson (1996) indicates that it is reasonable to assume high consumption rates of some foods whilst median values are assumed for other pathways. Because different radionuclides have different accumulation properties in different foodstuffs, it is reasonable to define a number of exposure groups with preferences for different combinations of foodstuff. Ideally the identification of the consumption preferences should be linked to some aspect of environmental accumulation – it is considered reasonable to set high consumption of fruit by the producer of the fruit, high consumption of milk by the producer of milk etc., since these individuals would also be at the location of the environmental concentration linked to the production of the foodstuff.

### C3.4.4. Identification of groups

General "rules-of-thumb" (see Section B5 of Part B) are suggested as the basis for the definition of suitable exposure groups. However, additional, application-specific information, should also be employed. Where such information is available. This is supplied by the assessment context and biosphere system description. From this material a "word-picture" description was developed for ERB2A, as follows:

> *The community is a modern agricultural community living in an area of about 10 km$^2$ (10,000 hectares) numbering between 300 and 1000 people living in small farms. The land, vegetation and animals of interest are those managed within the farms which become contaminated through the use of the well water. Within the community, it is possible to distinguish different groups from each other by the type of activities they mainly perform, including food production, leisure and rest activities. They are able to produce all foodstuff requirements, including milk, meat, fruits, root and green vegetables, cereals, animal feeds, etc., from within the contaminated area. (Modern*

*farming practice would permit production of the amount of foodstuffs consistent with the assumed population level.) The community is able to trade with other communities and can obtain machinery, manufactured materials and other necessities of modern life including those necessary to maintain modern agricultural practice in the developed world.*

*Common activities within the community include farming activities such as: ploughing, planting, tilling, applying herbicides and pesticides, irrigating the fields, reaping and looking after farm animals, all occurring over contaminated land. Leisure and rest activities can also occur over land which has become contaminated.*

Using Rule 1, the villagers consume all foodstuffs at median levels and the modelling choice is made to identify different types of farm with the type of produce derived therefrom. Rule 2 implies that farmers producing a certain type of produce consume this produce at the 97.5$^{th}$ percentile of the distributions.

Rule 3 implies locational exposures should be associated with areas of contaminated land – each farmer and/or farm family spends high amounts of time on their own farm (Rule 6). As shown below, Rules 4 and 5 can be used to partition time between different activities.

The word-picture implies that there are a number of farms since there are between 300 and 1000 people and the community is a modern farming community. It is not inconsistent to assume that different farms concentrate on different kinds of produce.

In the absence of more detailed information the following group activities are associated with candidate critical groups:

— *Livestock farms:* farms producing meat and dairy products from livestock provide the basis for this of exposure group. This allows high consumption of meat, offal and dairy products. Other consumption rates may be assumed to be at the median levels (Rules 1 and 2). Occupational exposures are those associated with animal husbandry.

— *Root and cereal crop farms:* farms producing root vegetables and cereals. Consumption via these two generic pathways provides the basis for critical consumption. Occupational exposures are those associated with crop production – ploughing, irrigating, harvesting, storage, etc.

— *Horticultural producers:* farms producing fruit and green vegetables. Critical consumption via these pathways defines another type of group. Occupational exposures are associated with horticultural production - ploughing, irrigating, harvesting, storage, etc.

— *Villager/Kitchen Garden:* it may be assumed that some of the villagers produce their own food. Root crops and green vegetables are the generic food types consumed at high rates. Rather than occupational pathways, this type of food production may be assumed to be recreational.

— *Villager:* generic village activities provide a median level food consumption baseline. From Rules 3 and 4 the non-consumption pathways should be highlighted by this group, to the extent that this behaviour is not included in any of the other groups.

Table C13 links pathways to five exposure group activities, with livestock involving five sub-groups. Further review should determine the extent to which it is necessary to model different animal types explicitly.

TABLE C13. ERB2A CANDIDATE CRITICAL GROUPS IDENTIFIED BY ACTIVITY

| | | | **EG1-1 beef / dairy** | **EG1-2 sheep** | **EG1-3 goats** | **EG1-4 pigs** | **EG1-5 poultry** | **EG2 arable farmer** | **EG3 hort. prod'er** | **EG4 villager KG** | **EG5 villager** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumption pathways** | | Cattle meat | ***critical*** | central | central | central | central | central | central | central | central |
| | | sheep/goat meat | central | ***critical*** | ***critical*** | central | central | central | central | central | central |
| | | pig meat | central | central | central | ***critical*** | central | central | central | central | central |
| | | poultry | central | central | central | central | ***critical*** | central | central | central | central |
| | | offal † | ***critical*** | ***critical*** | ***critical*** | ***critical*** | ***critical*** | central | central | central | central |
| | | fruit | central | central | central | central | central | central | ***critical*** | ***critical*** | central |
| | | root veg. | central | central | central | central | central | ***critical*** | central | central | central |
| | | green veg. | central | central | central | central | central | central | ***critical*** | ***critical*** | central |
| | | cereals | central | central | central | central | central | ***critical*** | central | central | central |
| | | water | central | central | central | central | central | central | central | central | central |
| | | milk | ***critical*** | ***critical*** | ***critical*** | central | central | central | central | central | central |
| | | milk products | ***critical*** | ***critical*** | ***critical*** | central | central | central | central | central | central |
| | | eggs | central | central | central | central | ***critical*** | central | central | central | central |
| | | soils (directly and indirectly) | central | central | central | central | central | central | central | central | central |
| **Inhalation** | **Occupa-tional** | plant burning - outdoors | no | no | no | no | no | yes | no | no | no |
| | | ploughing / digging irrigated land | no | no | no | no | no | yes | yes | no | no |
| | | irrigating irrigated land | yes * | yes * | yes * | no | no | yes | yes | no | no |
| | | general farm work near water storage | yes | yes | yes | yes | yes | yes | yes | no | no |
| | | general farm work on irrigated land | yes * | yes * | yes * | no | no | yes | yes | no | no |
| | | plant processing and storage indoors | yes * | yes * | yes * | yes ** | yes ** | yes | yes | no | no |
| | | animal husbandry, product processing and storage | yes | yes | yes | yes | yes | no | no | no | no |
| | | harvesting on irrigated land | yes * | yes * | yes * | no | no | yes | yes | no | no |
| | | milking indoors | yes * | yes * | yes * | no | no | no | no | no | no |
| | | manuring (indoors and outdoors) | yes * | yes * | yes * | no | no | yes | yes | no | no |
| | **Rec.** | out-door activities on irrigated land | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | outdoor digging (gardening) | no | no | no | no | no | no | no | yes | no |
| | | watering the garden | no | no | no | no | no | no | no | yes | no |
| | **Domestic** | general domestic activities (ambient dust levels) | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | general domestic activities (elevated dust levels) | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | domestic showering/bathing/sauna | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | cooking | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | domestic activities involving the use of water | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | **Sleeping** | | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| **External** | **Occupational** | general farm work on irrigated land (unshielded) | yes * | yes * | yes * | yes * | yes * | yes | yes | no | no |
| | | general farm work on irrigated land (shielded) | no * ¶ | no * ¶ | no * ¶ | no * ¶ | no * ¶ | no ¶ | no ¶ | no ¶ | no |
| | | general farm work near water storage body | no †† | no †† | no †† | no †† | no †† | no †† | no †† | no | no |
| | | plant processing & storage indoors | yes * | yes * | yes * | yes * | yes * | yes | yes | no | no |
| | | animal husbandry & product processing (indoor) | yes | yes | yes | yes | yes | no | no | no | no |
| | | clothing | yes | yes | yes | yes | yes | yes | yes | no | no |
| | | general indoor – no external sources | yes | yes | yes | yes | yes | yes | yes | no | no |
| | **Rec.** | out door activities on irrigated land | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | clothing | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | **Dom** | general indoor activities – no external source | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | proximity to stored plant and animal materials | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | domestic – clothing | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | | bathing/showering/sauna | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| | **Sleep** | sleeping under bedding | yes | yes | yes | yes | yes | yes | yes | yes | yes |

Notes:

* If pasture land is irrigated.

** Fodder.

† Offal taken from foodstuff corresponding to food consumed at critical consumption rate.

†† Ruled out because the dose model does not include proximity to water sources, only to immersion in water.

¶ Ruled out because the current dose model does not include explicit representation of this exposure.

Rec. Recreational usage. Sleep Sleeping.

Dom. Domestic. KG Kitchen Garden

### C3.4.5. Outline of exposure group (EG) behaviour

*Livestock farmers – EG1*

Livestock farmers consume median amounts of all foodstuffs except meat and offal (from their type of livestock – beef cattle, sheep, goats, pigs, poultry, etc.) as well as milk and dairy products where appropriate (pigs and poultry do not produce milk).

Inhalation doses arise from occupancy of farmland – tending livestock as well as, potentially, from inhaling aerosols whilst watering the herd and also from soils if irrigation of pasture is carried out. Recreational use of irrigated land also contributes to dose. Inhalation in the domestic environment, including during sleep should also be included.

External doses arise from the proximity to livestock (and soils if pasture is irrigated), as well as from the domestic environment arising from aerosols from the water supply.

*Arable farmers – EG 2*

Arable farmers consume central quantities of all foodstuffs except root vegetables and cereals which are consumed at critical levels.

Inhalation dose arises from occupational activities during occupancy of contaminated soils in general farm work, during ploughing and digging, harvesting and as a result of plant produce storage. Irrigation application may lead to inhalation doses during irrigation or work near water storage equipment. Recreational usage is also taken into account. All activities in the domestic environment are included, as is sleeping.

External doses arise during occupancy of contaminated soils and during periods of proximity to stored plant materials. Clothing during work time may also contribute. Recreational use of contaminated soils contributes to external dose as does clothing. In the domestic environment, general indoor activities, clothing, bathing and showering contribute. Also potentially included is domestic proximity to stored, potentially contaminated material e.g., grain stores. Doses from sleeping under blankets made from contaminated sources may also be considered.

*Horticultural producers – EG3*

Arable farmers consume central quantities of all foodstuffs except green vegetables and fruits which are consumed at critical levels.

All other pathways are conceptually similar to those of arable farmers with the exception that stubble burning has no counterpart and so is not included. It should be noted, however, that the areas of land involved in these exposures will be different to those involved in the arable farmer group and could, depending on the representation of the radionuclide transport model, be contaminated to a greater or lesser degree.

*Villager with kitchen garden – EG4*

Likely crops grown by the villager are root vegetables and green vegetables. These are consumed at critical rates. All other foodstuffs are consumed at central rates.

Villagers are not assumed to work on potentially contaminated land since this pattern of behaviour is subsumed into agricultural groups. In contrast to the agricultural groups, it may be assumed that recreational time is spent in the kitchen garden. Some recreational time may be spent on contaminated agricultural soils. Domestic and sleeping inhalation exposures may be taken to be similar to those of other groups since there is no conceptual difference.

External doses during work time for the villager groups are not included for similar reasons. Recreational, domestic and sleeping doses follow a similar pattern to that of the agricultural groups.

*Villager – EG5*

The villager group provides a background level of exposure. For reference, all consumption pathways are set to central levels.

No occupational time is spent on contaminated soils and the garden is not cultivated. Recreational time is spent on contaminated farmland. This is the source of inhalation and external doses during recreational time. Domestic and sleeping activities also give rise to inhalation and external doses, in a similar way to the other groups.

### C3.4.6. Locations and sources of exposure – utilisation of the environment

It may be necessary to distinguish different environmental concentrations involved in each pathway –soils used for root crop production may be contaminated to a different extent to soils used for fruit production. This impacts only on the consumption pathways, by way of the concentration in the consumed foodstuff, but also on the inhalation pathways.

Sources of foodstuff production are linked to occupational exposures (for farming exposure groups) and also may be associated with recreational activities. Domestic activities (including sleeping) are not likely to occur on directly irrigated soils and so separate areas must be allowed for in the conceptualisation of exposure group activities.

Table C14 shows how the exposure groups are linked to areas in the ERB2A system. Note that the five potential livestock farming groups have similar interactions. It is the relative strengths of these interactions which distinguish the groups. Further consideration must also be given to the route by which animal products may become contaminated. Table C14 indicates livestock soils, with the implication that animals are linked to sources of grazing but it is also that case that other foodstuffs may be used as fodder for livestock – cereals and root vegetables for cattle, cereals for poultry, general produce for pigs. It is assumed for simplicity that pigs are not included in ERB2A exposure group assessment.

It is nevertheless assumed that cows, sheep and goats are fed only on locally produced pasture. Poultry are fed on locally produced grain. Additional modelling assumptions are required to complete the description of the behaviour of human exposure groups in respect of how they manage their livestock.

TABLE C14. ASSOCIATION OF EXPOSURE GROUPS WITH LOCATIONS

| **EG1 – Livestock Farmers (including sub-groups 1 – 5)** | | | | | |
|---|---|---|---|---|---|
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | tending livestock | rec. activities | – | – |
| root crop soils | all root crops | – | rec. activities | – | – |
| cereal soils | all cereals | – | rec. activities | – | – |
| green veg. soils | all green veg | – | rec. activities | – | – |
| fruit soils | all fruit | – | rec. activities | – | – |
| irrigation/water sources | all water | livestock watering | rec. activities | domestic activities | – |
| farm yard environment | – | tending livestock | – | – | – |
| garden soils | – | – | – | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | – | – | – | – |
| **EG2 – Arable Farmers** | | | | | |
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | – | rec. activities | – | – |
| root crop soils | all root crops | agriculture | rec. activities | – | – |
| Cereal soils | all cereals | agriculture | rec. activities | – | – |
| green veg. soils | all green veg | – | rec. activities | – | – |
| fruit soils | all fruit | – | rec. activities | – | – |
| irrigation/water sources | all water | agriculture | rec. activities | domestic activities | – |
| farm yard environment | – | agriculture | – | – | – |
| garden soils | – | – | – | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | – | – | – | – |
| **EG3 – Horticultural Producers** | | | | | |
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | – | rec. activities | – | – |
| root crop soils | all root crops | – | rec. activities | – | – |
| cereal soils | all cereals | – | rec. activities | – | – |
| green veg. soils | all green veg | horticulture | rec. activities | – | – |
| fruit soils | all fruit | horticulture | rec. activities | – | – |
| irrigation/water sources | all water | agriculture | rec. activities | domestic activities | – |
| farm yard environment | – | agriculture | – | – | – |
| garden soils | – | – | – | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | – | – | – | – |
| **EG4 – Villagers with Kitchen Garden** | | | | | |
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | – | rec. activities | – | – |
| root crop soils | – | – | rec. activities | – | – |
| cereal soils | all cereals | – | rec. activities | – | – |
| green veg. soils | – | – | rec. activities | – | – |
| fruit soils | all fruit | – | rec. activities | – | – |
| irrigation/water sources | all water | – | rec. activities | domestic activities | – |
| farm yard environment | – | – | – | – | – |
| garden soils | all root & green veg. | – | gardening | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | occupational activities | – | – | – |
| **EG5 – Villagers** | | | | | |
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | – | rec. activities | – | – |
| root crop soils | all root crops | – | rec. activities | – | – |
| cereal soils | all cereals | – | rec. activities | – | – |
| green veg. soils | all green veg | – | rec. activities | – | – |
| fruit soils | all fruit | – | rec. activities | – | – |
| irrigation/water sources | all water | – | rec. activities | domestic activities | – |
| farm yard environment | – | – | – | – | – |
| garden soils | – | – | – | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | occupational activities | – | – | – |

* Including associated soil intake.

### C3.4.7. Review and iteration

The above qualitative description of exposure group activities corresponds to stage four of the BIOMASS Methodology given in Part B. Before finalising the descriptions, a review is recommended with iteration if necessary. The aim is to simplify the descriptions and to consolidate groups by subsuming those with similar characteristics.

The different livestock farmer groups may be combined into a single group. The requirement is that both meat and dairy production is possible from the chosen type of livestock. Given the modern farming requirement of the assessment context, beef and dairy cattle are suggested although sheep and goats are also possible. Investigation of the impact of the alternative animal types is a candidate for a sensitivity analysis in the context of the ERB2A model.

All the exposure groups identified above are comprised of adults. There has been some debate about the use of groups comprising different age groups. For example, it is not clear if the sometimes greater dose coefficients for younger humans outweigh the reduced intake. There is also the question of direct soil intake by children. The Methodology is used here to derive characteristics for an infant group, of 6–12 months age.

Table C15 provides the association between areas to be modelled and activities leading to infant exposure. A feature of this infant group is that it should be able to interact with irrigated soils (so as to emphasise the intake of activity in soil – a recognised feature of childhood behaviour). Farm soils could suffice in terms of recreational activity, but it is more reasonable to assume that children of this age group would spend their time around the domestic environment and so the choice is made to place the group in the village but to associate them with irrigated domestic soil i.e. with the kitchen garden exposure group. Farm produce comes from the livestock and arable farms but root and green vegetables are taken from the kitchen garden source. All consumption rates are set to median values. Note that even median levels of soil consumption for infants are higher than for adults (Simon, 1998).

TABLE C15. ASSOCIATION OF INFANT GROUP ACTIVITIES WITH LOCATIONS

| EG: Infant (Villagers with Kitchen Garden) | | | | | |
|---|---|---|---|---|---|
| | ingestion | inhalation and external | | | |
| Locale | consumption* | occupational | recreational | domestic | sleeping |
| livestock / livestock soils | all animal products | – | – | – | – |
| root crop soils | – | – | – | – | – |
| cereal soils | all cereals | – | – | – | – |
| green veg. soils | – | – | – | – | – |
| fruit soils | all fruit | – | – | – | – |
| irrigation/water sources | all water | – | – | domestic activities | – |
| farm yard environment | – | – | – | – | – |
| garden soils | all root & green veg. | – | playing | – | – |
| domestic environment | – | – | – | domestic activities | sleeping |
| village | – | – | – | – | – |

## C3.5. MODEL DEVELOPMENT FOR ERB2A

### C3.5.1. Conceptual model for radionuclide transfer

As a starting point, consideration was first given to the nature of the endpoint(s) under consideration; in this case individual radiation doses to members of potential exposure groups. Such radiation doses can occur via any of four principal radiation exposure modes: ingestion, inhalation, external irradiation, and by transfer of radionuclides through the skin, by puncture or absorption. Provisionally, all four modes should be considered, but the fourth one is not considered further here on the basis of its low significance (BIOMOVS II, 1996a).

The following Conceptual Model Objects have been identified from the biosphere system description:

- *Aquifer*, as the source of contamination.
- *Water Storage and Distribution System*, representing the means by which water is made available throughout the year for domestic use, animal watering and crop irrigation.
- *Atmosphere*, including the open air and confined spaces.
- *Cultivated Soil*, including all managed farmland.
- *Food and Fodder Crops*, grown in the cultivated soil, which are assumed to be irrigated by contaminated water.
- *Farm Animals*, including poultry, which may be watered from the contaminated source or eat contaminated fodder crops grown on irrigated land.
- *Farm Product Storage*, distribution and processing system, representing an important link in the chain of contamination to human exposure.
- *Sinks*, representing losses of radioactive contamination from the biosphere system resulting from processes such as radioactive decay, downward percolation of contaminated water, consumption in food and atmospheric transport.

From the perspective of describing radionuclide transfer, the presence of people is of comparatively limited importance compared with the objects identified above. People might potentially be included as part of the transfer pathway from foodstuffs to soil (via sewage), or perhaps as a secondary contaminant transfer pathway associated with the movement of soil attached to clothing. Overall, however, it was considered that such pathways of 'transfer via humans' would not represent a significant contribution to the overall environmental distribution of radionuclides within the biosphere system. This conclusion is especially valid if cautious simplifying assumptions (e.g. no removal of activity from soil in harvested crops) are employed in the model.

Nevertheless, it should be noted that the role of human activities in the distribution of radionuclides (e.g. via ploughing and irrigation) is implicit in the transfer processes between other different components of the biosphere system. Moreover, human behaviour leading to exposure, and corresponding exposure groups, are explicitly incorporated at a later stage in the development of conceptual models for radiological exposure.

The principal elements of the conceptualised biosphere system were then transferred to the leading diagonal elements of an Interaction Matrix. This allowed potential radionuclide transfer pathways to be investigated by representing them as off-diagonal elements of the matrix. The results of this are shown in Figure C8[13].

[13] References to C, I and Cl arise because radionuclides of these elements were initially included in ERB2A.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Aquifer | Water abstraction | x | x | x | x | x | Ingestion | x |
| 2 | x | Water Storage and Distribution System | Volatilisation (I, C, Cl) Degassing (Rn) | IrrigationSediment transfer | Irrigation and interception | Drinking waterSediment consumption | x | x | DecayHuman consumption |
| 3 | x | x | Atmosphere (external &\ internal) | Vapour / aerosol deposition | Vapour / aerosol deposition | Vapour / aerosol inhalation | x | Vapour / aerosol inhalation | DecayAdvection |
| 4 | x | x | SuspensionVolatilisation (I, C, Cl) Gas (Rn) | Cultivated Soil | Root uptakeSoil splash | Consumption of soil on fodder crops | Transfer of soil on crops | Ingestion | DecayLeaching / percolationErosion |
| 5 | x | x | Transpiration (3H)Respiration (14C) | WeatheringLeaf litterPloughed-in detritus | Food and Fodder Crops | Ingestion of fodder | Harvesting | Ingestion | Decay |
| 6 | x | x | Eructation (14C) | Manuring | x | Farm Animals | SlaughteringMilkingEgg collect | Ingestion | Decay |
| 7 | x | x | Volatilisation (I, C, Cl) | Green manuring / composting | x | Consumption of stored fodder | Farm product storage distribution & processing | x | ConsumptionDecaySilage leachate |
| 8 | x | x | Respiration | Excretion | x | x | x | Human Cummunity | x |
| 9 | x (Recharge) | x | x | x | x | x | x | x | Sinks |

*FIG. C8. Radionuclide Transfer Interaction Matrix.*

Notes on the Radionuclide Transfer Interaction Matrix

'x' = not relevant

*Leading diagonal elements*

Water Storage (2,2) incorporates: Evaporation, Sorption, Sedimentation, Precipitation and Dissolution
Atmosphere (3,3) incorporates: Filtration, Controlled Ventilation
Cultivated Soil (4,4) incorporates: Sorption, Ploughing, Bioturbation, Water Balance (Infiltration, Macropore Flow, Capillary Rise), Freeze/thaw Phenomena
Food and Fodder Crops (5,5) incorporates: Translocation
Farm Animals (6,6) incorporates: Metabolism
Farm Product Storage, Distribution and Processing System (7,7) incorporates: Food Processing

*Off diagonal elements*

'Sediment' in (4,2 ) and (6,2) relate to accumulated sediment in tanks and ponds.
Transfer from stored crops to atmosphere (7,3) is likely to be low by comparison with standing crop / bare soil owing to low surface area for release.
Potential loss/transfer of radionuclides to atmosphere from crops (5,3) and animals (6,3) is limited to $^{14}C$, since $^{3}H$ is excluded by the assessment context. Note that, in principle, many pathways for $^{14}C$ will be quite different from those for other radionuclides.
Transfer from animals to crops (6,5) would be potentially relevant if pasture were included. Although animals may be released into fields for consumption of fodder crop, possible transfer rates to standing crop will be small and can in any case readily be subsumed through other modelling assumptions.
Green manuring (7,4) is the use of silage leachate or excess crops for fertilisation and soil improvement.
Row 9 shows only 'x' (otherwise the sinks would not be sinks); however, it is noted that recharge phenomena should not be completely ignored if consistency is to be demonstrated between the biosphere and geosphere components of the assessment.

### C3.5.2. Auditing the radionuclide transfer interaction matrix

#### *C3.5.2.1. Comparison with the biosphere system description*

Those components of the Biosphere System Description previously considered to be relevant to the assessment model (i.e. those marked 'Y' in column 3 of Table C10) are listed separately in Table C16. This table classifies the components as 'implicit' or 'explicit', depending on whether they are associated with, respectively, leading diagonal elements or off-diagonal elements of the Radionuclide Transfer Interaction Matrix.

For the most part, all the relevant components appear in the Interaction Matrix, with a significant number being implicitly associated with that part of the model corresponding to radionuclide behaviour in cultivated soil. In developing the corresponding mathematical model of radionuclide transfer, it is necessary to ensure that all relevant FEPs, whether implicit or explicit in the Matrix, are appropriately addressed.

#### *C3.5.2.2. Comparison with independent FEP list*

The International FEP list (as presented in (BIOMASS, 1998c)) was next examined. All FEPs listed before Item 3.1.3 in the list (Cycling and Distribution of Materials in Living Components) are concerned with, and accommodated within, the system identification and description (Tables C9 and C10). The remaining FEPs within the list are addressed in the Radionuclide Transfer Interaction Matrix as described in Table C17.

#### *C3.5.2.3. Comparison with the updated biosphere system classification scheme*

Particular attention was given during the development of ERB2A to scrutinising the Radionuclide Transfer Interaction Matrix in the light of the parallel development of the system for classification and description of the living components of the biosphere system. (This is documented in BIOMASS Theme 1 Working Material). It was concluded that all the Ecology components, in so far as they were relevant to the assessment context and with the exception of arboriculture (orchard crops), had been included in the interaction matrix. It was decided that orchard crops should be excluded from the model because (i) such crops – grown locally – are not a major part of a mixed diet in most Temperate climates and (ii) they are, in any event, unlikely to be irrigated in the context of a small farm. Moreover, because transfer factors for irrigated fruit are not believed to be significantly greater than those for field crops, their potential contribution to overall radiological impact can readily be subsumed within other locally-grown components of the diet. This latter assumption ultimately needs to be confirmed.

All the elements of the Radionuclide Transfer Interaction Matrix could be cross-referenced to the System Description output. It was therefore concluded that the Interaction Matrix could be shown to contain all the FEPs identified as being relevant to a model description of radionuclide transfer.

## TABLE C16. COMPONENTS OF THE BIOSPHERE SYSTEM DESCRIPTION INCLUDED IN THE CONCEPTUAL MODEL

| Biosphere System Component (Table II etc.) | Descriptive Class | How included in the model |
|---|---|---|
| Climate Characteristics | Temperature<br>Precipitation<br>Pressure<br>Solar radiation | Secondary characteristics affecting evaporation, transpiration, the required amount of irrigation, etc. |
| Temporal variability of climate | Diurnal<br>Seasonal | Secondary characteristics affecting evaporation, transpiration, the required amount of irrigation, etc. |
| GII Consolidated/ Solid Geology | Lithostratigraphy<br>Fracture systems<br>Degree of weathering erodability<br>Deposition rates<br>Mineralogy | Secondary characteristics that are relevant insofar as they affect soil parameters. |
| Unconsolidated/ Drift Geology | Lithostratigraphy<br>Fracture systems<br>Degree of weathering erodability<br>Deposition rates<br>Mineralogy | Secondary characteristics that are relevant insofar as they affect soil parameters. |
| Soil | Stratification (e.g. soil horizons)<br>Composition (organic content, mineralogy)<br>Texture<br>Areal variation | Soil is a primary element of the conceptual model (4,4). Individual characteristics listed here affect soil-related parameters used in the model. |
| Human Activities | *Recycling and mixing of bulk materials*<br>– Ploughing<br>– Well<br>– Irrigation<br>– Recycling of bulk solid materials<br>– Controlled ventilation<br>*Redistribution of trace materials*<br>– Waste water treatment and use in manuring<br>– Air filtration<br>– Food processing | <br>Affects soil properties (4,4)<br>Incorporated under abstraction from well (1,2)<br>Explicit in matrix (2,4) and (2,5)<br>Explicit in matrix (6,4) and (7,4)<br>Affects mixing of atmosphere (3,3)<br><br>Subsumed within recycling (6,4) and (7,4)<br>Affects atmosphere concentrations (3,3)<br>Affects food concentrations (7,7) |
| WIIa<br>Water Bodies | Basal characteristics<br>Suspended sediments<br>**Freeze thaw phenomena**<br>– Seasonal<br>– Snow pack development<br>**Hydrochemistry**<br>– Major ions<br>– Minor ions<br>– Organic compounds<br>– Colloids<br>– Sorption<br>– Precipitation / dissolution<br>–Mineralisation<br>– pH and Eh | Represented in storage system (2,2)<br>Represented in storage system (2,2)<br><br>Secondary components mostly affecting the structure of the soil.<br><br><br><br>Characteristics affecting parameters radionuclide distribution, uptake and metabolism. |
| Water Balance | Precipitation<br>Irrigation<br>Evaporation<br>Transpiration | Characteristic affecting irrigation requirements (2,5)<br>Explicit in matrix (2,4) (2,5)<br>Represented in soil water balance (4,4)<br>Represented in soil water balance (4,4); also (5,3) |
| Land surface f | Infiltration<br>Porous medium<br>Macropore flow | Affect soil water balance (4,4) |
| Land surface b | Interflow (throughflow) = storage | Affect soil water balance and irrigation requirements (4,4) (2,5) |

Note 1. Numbers in parentheses (RH column) relate to corresponding off-diagonal-element in the radionuclide transfer matrix (Figure C8).

TABLE C17. CHECKLIST FOR APPEARANCE OF FEPS FROM THE INDEPENDENT FEP LIST IN THE RADIONUCLIDE TRANSFER INTERACTION MATRIX

| FEP | Where included |
|---|---|
| Root uptake (3.1.3.1.1) | Soil to plant transfer (4,5) |
| Respiration (3.1.3.1.2) | Plant to atmosphere (5,3) |
| Transpiration (3.1.3.1.3) | Plant to atmosphere (5,3); Soil water balance (4,4) |
| Intake by Fauna (3.1.3.1.4) | Consumption / inhalation (2,6) (3,6) (4,6) (5,6) |
| Interception (3.1.3.1.5) | Irrigation (2,5); Aerosol deposition (3,5) |
| Weathering (3.1.3.1.6) | Plant to soil transfer (5,4) |
| Bioturbation (3.1.3.1.7) | Soil process (4,4) |
| Translocation (3.1.3.2.1) | Fodder crop models (5,5) |
| Animal metabolism (3.1.3.2.2) | Animal models (6,6) |
| Evaporation (3.1.4.1.1) | Soil water balance (4,4); Stored water (2,2) |
| Gas transport (3.1.4.1.2) | Atmosphere (3,3) (3,8); also (4,3) (5,3) (6,3) |
| Aerosol transport (3.1.4.1.3) | Soil to atmosphere (4,3) (3,3) (3,8) |
| Precipitation (3.1.4.1.4) | Input to infiltration => soil water balance (4,4) |
| Wet/dry deposition (3.1.4.1.5/6) | Atmosphere to soil/plant (3,4) (3,5) |
| Infiltration (3.1.4.2.1) | Soil process (4,4) |
| Percolation (3.1.4.2.2) | Soil process (4,4) |
| Capillary rise (3.1.4.2.3) | Soil process (4,4) |
| Erosion (3.1.4.2.10) | In this model represents a transfer to sink (4,9) |
| Sedimentation (3.1.4.3.2) | Stored water process (2,2) |
| Suspension (3.1.4.3.3) | Stored water process (2,2) |
| Rain splash (3.1.4.3.4) | Soil splash (4,5) |

Note 1. Numbers in parentheses in the LH column are the FEP references. Numbers in parentheses in the RH column relate to the corresponding off-diagonal-element in the radionuclide transfer matrix (Figure C8).

*Water storage and distribution system*

A variety of FEPs have been identified in the conceptual model that could potentially change the concentration of radionuclides in the water supply, compared with that in the abstracted well water. These include evaporation of the water, sorption onto sediments or other surfaces, sedimentation, precipitation and dissolution.

Evaporation of water during storage and distribution might give rise to a small increase in concentration of those radionuclides remaining in solution. However, total water losses via this route are considered unlikely to be significant in a Temperate environment, and the process is not included in the model.

Although suspended sediment may be present within the water supply, the total sediment load must be low enough for the water to remain potable (since no deliberate water treatment is assumed to take place). Sorption onto suspended sediment, and subsequent sedimentation, may occur over time; however, the overall effect of this will only be to reduce radionuclide concentrations in bulk water supplied at the point of delivery. The periodic removal of accumulated sediments from cisterns and other parts of the storage and distribution system could potentially give rise to a transient ‘spike’ in water concentration resulting from the remobilization of radionuclides. This might possibly be relevant if the focus of interest were the dose from exposure within a specific year; over a longer period, however, the average concentration in the water supply will not exceed that delivered at the well head. Furthermore, any transfer of radionuclides associated with the possible removal to soil of accumulated sediment from within the water distribution system is unlikely to be significant, since the volumes involved will be comparatively small. Moreover, if the material is suitable for spreading on the land, sorption coefficients are unlikely to be significantly different from those for the irrigated soil itself. It will therefore be acceptable for this Example to ignore the effects of sorption and sedimentation in modelling radionuclide transfer within the water distribution system.

Precipitation and/or dissolution of radionuclides associated with changes to water chemistry (e.g. because of microbial action) may possibly affect concentrations in bulk water. Again, however, their net effect can only be to reduce radionuclide concentrations in bulk water compared with that delivered at the well head. Provided that the radionuclide concentration in bulk water (i.e. including suspended solids) is specified at the geosphere-biosphere interface (or can be calculated), it will therefore be cautious to ignore the effects of precipitation and dissolution in the radionuclide transfer model.

Potential exposures linked to contact with contaminated sediments and other surfaces within the water supply system are considered negligible compared with those associated with other contaminated media. This might be less easy to justify for an 'industrial' or 'commercial' biosphere system, in which maintenance of water storage, distribution and supply systems could potentially constitute a specialised job. However, the present assessment context excludes consideration of large-scale commercial/industrial activities. Hence, sorption and sedimentation within the water storage and distribution system can also be ignored in the context of evaluating radiological exposures.

The possible decay and in-growth of radionuclides within the water storage and distribution system could potentially affect the concentrations of certain short-lived radioactive progeny. It should therefore be cautiously assumed that such radionuclides (i.e. with half-lives comparable with, or shorter than, the mean time spent by water in such a system) are present in the water supply in equilibrium with their parents, whatever the original concentrations may have been at the well head.

Overall, therefore, there is no need for explicit representation of the water storage and distribution system within the biosphere model. For modelling purposes, it may be simply assumed that the water supply to other parts of the biosphere system is provided at the same bulk concentration, $Q_i$, as that delivered at the well head. The only exception to this is a modification, where necessary for short-lived progeny, as discussed in the paragraph above.

*Atmosphere*

Radionuclides may be transferred to atmosphere in various forms from other parts of the biosphere system. Contaminated aerosols in the form of radionuclides adsorbed to particular material may be derived from soils, as well as other material. Volatile forms of particular radionuclides (I, C, Cl) can potentially be released as vapour from soils, from product storage, or from the water storage and distribution. Gaseous forms (particularly $^{14}CH_4$ and $^{14}CO_2$, but also Rn) can also be released from soils, as well as from animals and plants. Wet or dry deposition processes then cause the vapour and/or aerosol to return to settle on or be absorbed by the land and other surfaces, plants, animals etc.

Concentrations of dust or trace materials in the atmosphere can vary rapidly over a considerable range according to local meteorological conditions (atmospheric pressure, wind speed, precipitation etc) as well as factors such as artificial disturbance (e.g. dusts generated by ploughing). The processes involved are complex; however, a significant proportion of the locally-generated transfer of aerosol and vapour will typically remain within a near-surface atmospheric boundary layer and not travel very far before being deposited again. Nevertheless, over time, such transport can lead to losses of radionuclides from the biosphere system; at the same time, other material will be brought into the system from outside by atmospheric processes. Because such transfers are expected to be small compared with, for example, irrigation and percolation in groundwater, it is considered appropriately cautious, without being excessively so, to make the simplifying modelling assumption that their effect can be ignored.

Such simplifications mean that there is no need for an explicit representation of atmospheric transfer processes, and no atmosphere compartment is therefore incorporated in the assessment model. However, radioactive vapour, gas or aerosol within the atmosphere can represent an inhalation hazard, which can potentially be a significant exposure pathway for some radionuclides. It is therefore appropriate to evaluate radionuclide concentrations in the near-surface atmospheric boundary layer, or in indoor atmospheres that may receive releases of gas or vapour. Standard practice is to represent the long-term equilibrium relationship between average atmospheric concentrations and those in soils, plants and other environmental media using empirical correlations.

*Arable crops*

Crops will become contaminated due to direct deposition of irrigation water. A fraction can be retained on the plant surface and another fraction be transferred within the plant, particularly to edible parts. Weathering of plant surfaces results in transfer of intercepted radionuclides to soil. Crops may then become contaminated by root uptake. Soil splash may result in further crop contamination. Although seasonal factors can substantially influence details of what could happen within any one year, given the nature of the time frames of interest as discussed above, all the above processes can be modelled on the basis of equilibrium between the concentration in the irrigation water and the concentration in crops, or between the soil and crops. Models, for this set of processes with the same type of context, commonly use this approach (BIOMOVS II, 1996b).

*Animals*

The same equilibrium approach is adopted for animal product contamination, with concentrations being directly related to concentrations in the irrigation water (for consumption of water but also contribution via crop contamination) or in soil (for contribution via crop contamination or direct ingestion).

*Cultivated Soil*

Cultivated soil is assumed to be ploughed, if not every year then every few years, consistent with the picture presented above. Given the time frames under consideration this means that detailed soil structure is not to be modelled. A “well mixed” layer is assumed associated with typical ploughing depths and to the dominant region in the profile for root uptake by crops and other biotic activity. Processes within the soil result in downward movement, primarily due to infiltration of water.

*Farm products in storage, distribution and processing systems*

Radionuclide behaviour in stores is not considered to be of great interest only producing a minor decay effect. However these assumptions for storage etc can affect how food is distributed (diluted) before consumption. Processing may result in changed concentrations in the foods/fodder.

TABLE C18. HUMAN EXPOSURE PATHWAYS

| Source | Pathway |
|---|---|
| Domestic Water | Ingestion<br>Spray Inhalation<br>Immersion (bathing)<br>External (exposure to storage/distribution system) |
| Irrigation Water | Spray Inhalation |
| Animal Water | Subsumed in other uses of water |
| Atmosphere | Suspended soil and other dust, vapour and gas inhalation (indoor and outdoor) |
| Cultivated Soil | Ingestion, with food product, and direct ingestion<br>External exposure |
| Crop in Field | External exposure |
| Animal in Field/Barn | External exposure |
| Food Products | External (e.g. silage clamp)<br>Ingestion |

### C3.5.3. Conceptual model for radiation exposure

In the case of exposure assessment, the items of interest correspond to a particular contaminated medium, rather than a physical location. Thus, for example, exposure to contaminated soil might arise from material that has been transferred on clothing from the land into the domestic environment. Based on the Radionuclide Transfer Interaction Matrix (Table C16), and the corresponding definitions for each leading diagonal elements, the following potentially contaminated media can be identified as qualitatively distinct sources of radiation exposure:

- water (for domestic use, animal watering and irrigation);
- atmosphere (indoor and outdoor);
- arable crops (in field);
- animals (in field or barn);
- cultivated soil;
- farm products in the storage, distribution and processing system.

Table C18 indicates the potential exposure pathways associated with each medium.

### C3.5.4. Mathematical model

#### *C3.5.4.1. Intercompartmental transfer processes*

The mathematical representation of the intercompartment transfer processes takes the form of a matrix of transfer coefficients which allow the compartmental inventories to be represented as a set of first-order linear differential equations. For the *i*th compartment, the rate at which the compartment inventory changes with time is given by:

$$\frac{dN_i}{dt} = \left( \sum_{j \neq i} \lambda_{ji} N_j + \lambda_N M_i + S_i(t) \right) - \left( \sum_{j \neq i} \lambda_{ij} N_i + \lambda_N N_i \right)$$

where:

$N_i$ is the activity of radionuclide $N$ in biosphere compartment $i$, Bq;
$N_j$ is the activity of radionuclide $N$ in biosphere compartment $j$, Bq;
$M_i$ is the amount of radionuclide $M$ in biosphere compartment $i$ ($M$ is the precursor radionuclide of $N$ in a decay chain), Bq;
$S_i(t)$ is an external source term of radionuclide $N$ to compartment $i$, Bq $y^{-1}$;
$\lambda_N$ is the decay constant for radionuclide $N$, $y^{-1}$;
$\lambda_{ji}$ is a set of transfer coefficients inputs to compartment $i$ from the other $j$ $(\neq i)$ compartments in the system, $y^{-1}$;
$\lambda_{ij}$ is the set of transfer coefficients representing the loss terms of $N$ from compartment $i$ to the other $j$ $(\neq i)$ compartments of the system and to sinks.

The intercompartment transfer rate coefficients ($\lambda_{ij}$) are the mathematical representation of the transfer processes identified in the conceptual model. The processes described in the conceptual model are taken into account on a unit area ($m^2$) basis. For example, we consider irrigation rates and crop production on a unit area basis and then assume that sufficient crops are produced to support the exposed group(s). In fact, in this Example we assume only one compartment representing cultivated soil. There are a number of loss mechanisms from this soil, as well as radioactive decay and ingrowth, to calculate.

*C3.5.4.2. Process representation*

*Irrigation source term*

Irrigation water is assumed to be applied to cultivated soil at a rate $V_{irr}$ $m^3$ $y^{-1}$. This volume rate is that applied to 1 $m^2$ of soil. Although a fraction of irrigation water is intercepted by crops, all the activity in the water is assumed to enter the soil immediately. The relatively minor delay before weathering removes intercepted activity to the soil is ignored so far as the concentration in soil calculation is concerned. The proportion of intercepted activity which is absorbed by the crop is also ignored so far as calculation of this concentration is concerned. It is assumed that plant material is recycled and incorporated into the soil. Changes in concentrations from well head to point of irrigation are also ignored. Thus, the source term to the soil due to irrigation, $S$, Bq $y^{-1}$, is given by:

$$S = V_{irr} C_w$$

where:

$C_w$ is the radionuclide concentration in the well water, Bq $m^{-3}$.

*Infiltration (and other downward losses) from cultivated soil*

The rate coefficient for the transfer of radionuclides out of cultivated soil due to infiltration $\lambda_{1I}$, $y^{-1}$ is given by:

$$\lambda_{1I} = \frac{I}{R\,\theta\,d}$$

where:

*I* is the annual infiltration/recharge rate, m $y^{-1}$;
*R* is the retardation coefficient for the cultivated soil compartment;
$\theta$ is the water filled porosity of the cultivated soil compartment;
*d* is the thickness of the cultivated soil compartment, m.

The R term is calculated using the following equation:

$$R = 1 + \frac{(1-\theta_t)\rho}{\theta} K_d$$

where:

$\theta t$ is the total porosity of the cultivated soil compartment;
$\rho$ is the grain density of the cultivated soil compartment, kg $m^{-3}$;
*Kd* is the sorption coefficient of the cultivated soil compartment, $m^3$ $kg^{-1}$.

It is noted that better data may be available for R than for *Kd* and related parameters. *Kd*'s determined from column experiments may be more relevant than batch experiments, being more likely to represent fully the effect of water moving through the soil.

*Erosion*

The rate coefficient for the transfer of radionuclides from cultivated soil to sinks (i.e. out of the system) by erosion $\lambda_{,1E}$, $y^{-1}$, is given by:

$$\lambda_{1E} = \frac{E}{d}$$

where:

*E* is the erosion rate for the soil compartment, m y-1.

Data for *E* consistent with the system description are in the range 1.7 $10^{-4}$ to $10^{-3}$ m $y^{-1}$, taking the landform and the soil to be non-sloping farmed chernozem (Jones, 1987). Taking *d* to be about 0.3 m, this implies a value for $\lambda_{1E}$ of about $10^{-3}$ $y^{-1}$. Since this is slow relative to a realistic time frame for continued irrigation of a specific area, it was decided to ignore this process in the model. However, while recognising the potential inappropriateness of an assumption of continuing irrigation over hundreds of years at one location, it was decided to include in the results the time taken for the annual individual dose rate to reach 90% of its equilibrium value, to see if accumulation in soil over a reasonable period of continual irrigation could be important relative to direct deposition onto growing plants during irrigation.

*Cropping*

In circumstances of high uptake of radionuclides from soils into growing plants, the concentration in soils would be modified. The activity in that proportion of plants not returned to soil through plant decay, i.e. the proportion removed in cropping, would be lost from the system. It is recognised that this process is only significant for those radionuclides which are significantly taken up into crops. The crops and pasture are assumed to be grown in rotation on the unit area of land. The rate constant for removal from the soil, $\lambda_{1C}$ $y^{-1}$, is given by:

$$\lambda_{1C} = \frac{\sum_{crop} \frac{1}{4}(CF_{crop} + S_{crop})Y_{crop}}{(1-\theta_t)\rho d}$$

where:

$CF_{crop}$ is the concentration factor from root uptake for the crop, Bq $kg^{-1}$ (fresh weight of crop)/Bq $kg^{-1}$ (dry weight of soil);
$S_{crop}$ is the soil contamination on the crop, kg (dry weight soil) $kg^{-1}$ (fresh weight of crop);
$Y_{crop}$ is the wet weight biomass of the crop, kg $y^{-1}$, obtained at harvest from the unit area irrigated.

Thus, the conceptual model of radionuclide transfer processes is illustrated in Figure C9 and the equation for the radionuclide concentration in the bulk cultivated soil compartment, $C_s$, for radionuclide $N$, Bq $m^{-3}$, is:

$$\frac{dC_s}{dt} = -\ (\lambda_N + \lambda_{1C} + \lambda_{1I})C_s + \frac{V_{irr}C_w}{d}$$

The additional rate constant for erosion, $\lambda_{1E}$, is ignored on the basis that it is either not significant compared to the other transfers or it is so low as to require the consideration of biosphere change before it would make have a significant affect on the radionuclide concentration of the soil compartment (see Annex CIII).

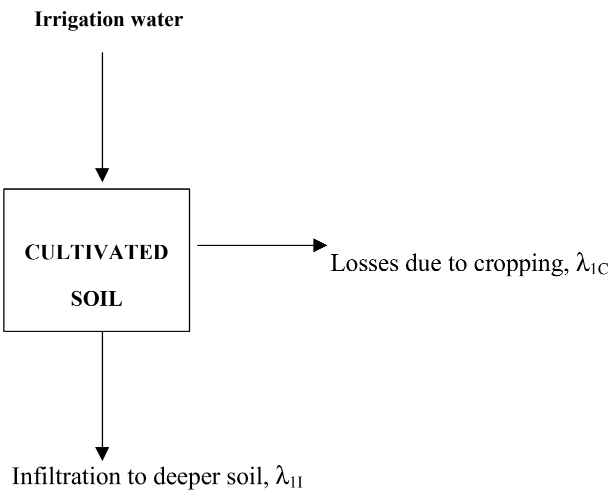


*FIG. C9. BIOMASS Theme 1, Conceptual Model of Transfer Processes for Example Reference Biosphere 2A.*

*C3.5.4.3. Dose equations*

*Consumption of drinking water*

The annual individual dose from the consumption of unfiltered drinking water from the well is given by:

$$D_w = ING_w \; DC_{ing} \; C_w$$

where:

$D_w$ is the individual dose from consumption of well water, Sv $y^{-1}$;
$ING_w$ is the individual ingestion rate of well water, $m^3$ $y^{-1}$;
$DC_{ing}$ is the dose coefficient for ingestion, Sv $Bq^{-1}$.

*Consumption of agricultural crops*

The annual individual dose from the consumption of agricultural crops is given by:

$$D_{crop} = ING_{crop} \; DC_{ing} \; C_{crop}$$

where:

$D_{crop}$ is the individual dose from consumption of the crop, Sv $y^{-1}$;
$ING_{crop}$ is the individual ingestion rate of the crop, kg $y^{-1}$;
$C_{crop}$ is the radionuclide concentration in the edible part of the crop, Bq $kg^{-1}$ (fresh weight of crop).

The $C_{crop}$ term is calculated using the following equation:

$$C_{crop} = \frac{(F_{p2}CF_{crop} + F_{p1}S_{crop})C_s}{(1-\theta_t)\rho} + I_{crop}V_{irr}C_w\left(\frac{(1-F_{abs})e^{-WT}F_{p3}}{Y} + \frac{F_{abs}F_{p2}F_{trans}}{Y}\right)$$

where:

$I_{crop}$ is the fraction of radionuclide in spray irrigation water that is initially deposited on standing biomass;
$F_{trans}$ is the fraction of absorbed activity that is translocated to the edible portion of the plant by the time of harvest (translocation fraction);
$F_{abs}$ is the fraction of intercepted radionuclide initially deposited onto the plant surface that is absorbed from external surfaces into plant tissues;
$F_{p1}$ is the fraction of external soil contamination on the edible part of the crop retained after food processing;
$F_{p2}$ is the fraction of the internal contamination associated with the edible part of the plant at harvest that is retained after food processing has occurred;
$F_{p3}$ is the fraction of external contamination from interception that is retained on the edible part of the crop after food processing;
$W$ is the removal rate of radionuclide deposited on plant surface by irrigation by weathering processes (weathering rate) including mechanical weathering, wash-off and leaf fall, $y^{-1}$;
$T$ is the interval between irrigation and harvest, y.

It should be noted that it is assumed that the crop can be contaminated due to:

— internal uptake of contaminants from the cultivated soil compartment into the crop via the roots (represented by the $\frac{CF_{crop}C_s}{(1-\theta_t)\rho}$ term);

— external contamination of the crop due to deposition of re-suspended sediment from the surface soil compartment (represented by the $\frac{S_{crop}C_s}{(1-\theta_t)\rho}$ term);

— irrigation (represented by the $I_{crop}V_{irr}C_w$ term).

It is assumed that contamination can be lost due to:

— food preparation (represented by $F_{p1}$, $F_{p2}$ and $F_{p3}$ terms);

— weathering of the external contamination to the soil (represented by the $e^{-WT}$ term).

An alternative to the $e^{-WT}$ formulation is applied for pasture, see below. This averages out processes on-going through the year, and is more appropriate in the case of pasture since cropping by cows or sheep would be continuous. Using $e^{-WT}$ allows the investigation of alternative assumptions for $T$, potentially more significant for crops directly consumed by humans.

*Consumption of animal produce*

The annual individual dose from the consumption of animal produce is given by:

$$D_{prod} = ING_{prod}\ DC_{ing}\ C_{prod}$$

where:

$D_{prod}$ is the individual dose from consumption of the animal product, Sv $y^{-1}$;
$ING_{prod}$ is the individual consumption rate of the animal product, kg $y^{-1}$;
$C_{prod}$ is the radionuclide concentration in the animal product, Bq $kg^{-1}$.

The $C_{prod}$ term is calculated using the following equation:

$$C_{prod} = TF_{proding}\left(C_{fodd}ING_{fodd} + C_w ING_{wa} + \frac{C_s\ ING_{sa}}{(1-\theta_t)\rho + \theta\rho_w}\right) + (BR_a O_{an} C_{airs})TF_{proding}$$

where:

$TF_{proding}$ is the transfer factor for ingestion for the animal product, d $kg^{-1}$ (fresh weight of product);
$C_{fodd}$ is the radionuclide concentration in the animal fodder, Bq $kg^{-1}$ (fresh weight of fodder);
$TF_{prodinh}$ is the transfer factor for inhalation for the animal product, d $kg^{-1}$ (fresh weight of product);
$ING_{fodd}$ is the consumption rate of fodder by the animal, kg (fresh weight) $d^{-1}$;
$C_w$ is the radionuclide concentration in the well water, Bq $m^{-3}$;

$ING_{wa}$ is the consumption rate of water by the animal, $m^3\ d^{-1}$;
$ING_{sa}$ is the consumption rate of soil from the cultivated soil compartment by the animal, kg (wet weight of soil) $d^{-1}$;
$\rho_w$ is the density of water, kg $m^{-3}$;
$BR_a$ is the breathing rate of the animal, $m^3\ h^{-1}$;
$O_{an}$ is the occupancy time of the animal in the cultivated soil compartment, h $d^{-1}$;
$C_{airs}$ is the radionuclide concentration in the air above the cultivated soil compartment, Bq $m^{-3}$.

The $C_{airs}$ term is calculated using the following equation:

$$C_{airs} = \frac{C_s}{(1-\theta_t)\,\rho} \frac{(R - 1)}{R} dust_s$$

where:

$dust_s$ is the soil derived dust level in the air above the cultivated soil compartment, kg $m^{-3}$.

The $TF_{prodinh}$ term is calculated using the following equation:

$$TF_{prodinh} = TF_{proding} \frac{f_L + f_C\, f_1(inh)}{f_1(ing)}$$

where:

$f_L$ is the fraction of inhaled activity reaching the systemic circulation of man following transfer across the lung lining;
$f_C$ is the fraction of inhaled activity that is cleared to the gastrointestinal tract of man; and
$f_1(inh)$ is the fraction of inhaled activity, cleared to the gastrointestinal tract, that is transferred to the systemic circulation of man;
$f_1(ing)$ is the fraction of ingested activity reaching the body fluids in man.

The nature of the fodder consumed by the animal depends on the type of animal. In this example, one animal type is considered, cows. It is assumed that the cows consume pasture. The $C_{fodd}$ term is calculated using the following equation:

$$C_{fodd} = \frac{(CF_{past} + S_{past})C_s}{(1-\theta_t)\rho} + \frac{I_{past}V_{irr}C_w}{SB_{past}W_{past} + 365\, ING_{fodd}SD}$$

where:

$CF_{past}$ is the concentration factor for pasture, Bq $kg^{-1}$ (fresh weight of pasture)/Bq $kg^{-1}$ (dry weight of soil);
$S_{past}$ is the soil contamination on pasture, kg (dry weight soil)/kg (fresh weight of pasture);
$I_{past}$ is the interception fraction for irrigation water on pasture;
$SB_{past}$ is the standing yield of pasture, kg;
$W_{past}$ is the removal rate of irrigation water from pasture by weathering (weathering rate), $y^{-1}$;
$SD$ is the number of animals in the area of interest;
$INGf_{odd}$ here, has to be multiplied by 365 to convert to intake as kg fw $y^{-1}$.

The following points should be noted.

- It is assumed that the animal can be contaminated due to:
- consumption of contaminated fodder (represented by the $C_{fodd}\,ING_{fodd}$ term);
- consumption of contaminated water (represented by the $C_w\,ING_{wa}$ term);
- consumption of contaminated soil (represented by the $\frac{C_s ING_{sa}}{(1-\theta_t)\rho + \theta\rho_w}$ term);
- inhalation of contaminated soil (represented by the $BR_a\,O_{an}\,C_{airs}$ term).

*Consumption of soil*

Apart from inadvertent consumption due to soil contamination of crops, soil can be consumed by humans both inadvertently and deliberately. The annual individual dose to humans from this type of soil consumption is given by:

$$D_{soil} = ING_{soil} DC_{ing} \frac{C_s}{(1-\theta_t)\rho + \theta\rho_w}$$

where:

$D_{soil}$ is the individual dose from consumption of the soil, Sv $y^{-1}$;
$ING_{soil}$ is the individual consumption rate of the soil, kg $y^{-1}$, wet weight.

*External irradiation from soil*

The annual individual dose to humans from external irradiation from soil/sediment, during occupancy of the soil compartment, is given by:

$$D_{exsoil} = O_s DC_{exts} C_s$$

where:

$DC_{exsoil}$ is the individual dose from external irradiation from the soil, Sv $y^{-1}$;
$O_s$ is the individual occupancy in the soil compartment, h $y^{-1}$;
$D_{exts}$ is the dose factor for external irradiation from soil, Sv $h^{-1}$/Bq $m^{-3}$.

*External irradiation from immersion in water*

The annual individual dose to humans from external irradiation from immersion in water (used to calculate the annual individual dose from bathing) is given by:

$$D_{imwat} = O_{wat}\ DC_{imw}\ C_w$$

where:

$D_{imwat}$ is the individual dose from external irradiation from immersion in the water, Sv $y^{-1}$;
$O_{wat}$ is the individual occupancy in the water, h $y^{-1}$;
$DC_{imw}$ is the dose coefficient for external irradiation from immersion in water, Sv $h^{-1}$ / Bq $m^{-3}$.

*Inhalation of dust*

The annual individual dose to humans from the inhalation of dust, during occupancy of the soil compartment, is given by:

$$D_{dust} = DC_{inh} BR\ O_s C_{airs}$$

where:

$D_{dust}$ is the individual dose from the inhalation of dust, Sv $y^{-1}$;
$DC_{inh}$ is the dose coefficient for inhalation, Sv $Bq^{-1}$;
$BR$ is the breathing rate of the human in the soil compartment, $m^3$ $h^{-1}$.

*Inhalation of aerosols/spray*

The annual individual dose to humans from the inhalation of aerosols in water spray is given by:

$$D_{aero} = DC_{inh} BR\ AIR_{aero} O_{aero} C_w$$

where:

$D_{aero}$ is the individual dose from the inhalation of aerosols, Sv $y^{-1}$,
$AIR_{aero}$ is the aerosol level in the air in the area affected by aerosols/spray, $m^3$ $m^{-3}$,
$O_{aero}$ is the individual occupancy in the area affected by aerosols, h $y^{-1}$.

### C3.5.5. Quantitative description of exposure groups

*C3.5.5.1. Consumption rates*

There are many potential sources of data for consumption rates. For example Robinson (1996) provides a comprehensive review of data specifically for use in radiological assessments. This publication provides very useful background material on which databases can be constructed, particularly as it quotes central and high consumption levels. However, it is not based on a survey of a population living under ZBVII conditions. ERB2A is a generic site in a ZBVII climate state and so data derived from a corresponding state should be adopted. The other requirement is that the database should correspond to modern farming practices as required by the assessment context.

A number of alternative databases have been suggested: MAPA (1993) and IAEA (1995, 1996 and 1999). These have the advantage that they have also been compiled and used in the context of radiological dose assessments. Other compilations (Bertrand, 1993; Combris et al., 1997; USDA, 1998) are comprehensive but their usage would require considerable additional interpretation and recombination of data. This is, in itself fraught with difficulties.

Of these, MAPA (1993) and IAEA (1995) include data corresponding to the ERB2A ZBVII climate state. IAEA (1999) provides data from a world-wide range of surveys and so is potentially useful.

The Spanish database (MAPA, 1993) contains the results of a detailed analysis of consumption which gives not only central values but also fitted distribution information from which it is possible to derive all statistical information. As such the high quality of this database strongly recommends itself for use in the Examples. However there is not a direct correspondence with the ERB2 pathways and, in the absence of the full survey data from which the database was derived, there are some difficulties in combining pathways to match the ERB2 requirements (for ERB2B as well as ERB2A).

IAEA (1995) shows a closer correspondence with the ERB2 pathways but there is no distribution information available. Application of the factor-of-three rule identified in Section C3.2 is therefore necessary. Comparisons of the consumption rate data from different surveys (including those referred to above) is provided in Part B. Differences in mean consumption rates are around a factor of 3 for the major components of diet and data in Robinson (1996), supporting the suggestion in Annex BII of Part B that there is a factor of about 3 difference between mean/median values and $95^{th}$/97.5 percentiles. Table C19 presents the recommended consumption values for use in the ERB2A calculations.

Total meat implies all meat consumption including offal. No value for offal is given so the Robinson (1996) value is adopted and this is subtracted from total meat. 0.8% and 0.3% of total meat is mutton and game (mostly rabbit) respectively. The total meat consumption is obtained with this knowledge of fractional dietary components from other sources.

Root vegetables are a combination of the IAEA (1995) value for potato and the 34% of 'vegetables' quoted in IAEA (1995) as being root vegetables. Green vegetables comprise the 24% of 'vegetables' quoted as leafy vegetables and the 42% quoted as 'other vegetables' in IAEA (1995).

*C3.5.5.2. Inhalation rates*

Data provided by Robinson (1996) distinguish between the general domestic environment, sleeping, general occupational rates, rates suitable for periods engaged in heavy work. A breakdown by sex and type of occupation is also given together with the amount of time spent in the different activities. The data from Robinson (1996) are reproduced in Table C20.

TABLE C19. CONSUMPTION RATE VALUES RECOMMENDED FOR THE ERB2A STUDY

| | Adult | | Infant | |
|---|---|---|---|---|
| *ERB2A categories* | Central | Critical | Central | Critical |
| Meat | 69.3 | 207.9 | 29.5 | 88.6 |
| Milk and dairy produce | 248.0 | 744.0 | 53.3 | 159.9 |
| Fish | 2.3 | 6.9 | 0.0 | 0.0 |
| Green vegetables[a] | 96.0 | 290.0 | 64.0 | 192.0 |
| Root vegetables | 105.5 | 316.5 | 51.6 | 154.7 |
| Cereals | 157.0 | 471.0 | 14.8 | 44.4 |
| Offal[b] | 4.5 | 13.5 | 0.6 | 1.8 |
| Soils[b] | 3.7E-03 | 8.3E-03 | 3.7E-02 | 4.4E-02 |
| Water[c] | 600 | 1200 | | 260 |

**Notes:**

Italicised pathways are relevant to ERB2B. 'Critical' values are obtained from the 'central' value multiplied by a factor of three. Data are from IAEA (1995) unless otherwise stated. All units are kg or y.

[a] The green vegetable values are approximately twice the values given in IAEA (1995) because fruit, as well as fungi and nuts, have been subsumed with green vegetables.

[b] Robinson (1996).

[c] BIOMASS ERB1.

TABLE C20. DAILY INHALATION RATES BY ACTIVITY WITH TIME SPENT DURING ACTIVITY (FROM ROBINSON (1996))

| location | activity | sedentary work | | | | | | heavy work | |
|---|---|---|---|---|---|---|---|---|---|
| | | housewife | | male | | female | | outdoor worker | |
| | | duration [h day$^{-1}$] | inhalation rate [m$^3$ h$^{-1}$] | duration [h day$^{-1}$] | inhalation rate [m$^3$ h$^{-1}$] | duration [h day$^{-1}$] | inhalation rate [m$^3$ h$^{-1}$] | duration [h day$^{-1}$] | inhalation rate [m$^3$ h$^{-1}$] |
| **Indoors** | | | | | | | | | |
| home | sleeping | 8.5 | 0.32 | 8.5 | 0.45 | 8.5 | 0.32 | 8.5 | 0.45 |
| work & | general | 13.5 | 0.96 | 7 | 1.18 | 9.5 | 0.96 | 7 | 1.18 |
| elsewhere | work, etc. | 1 | 0.96 | 6.5 | 1.18 | 4 | 0.96 | 1 | 1.18 |
| **Outdoors** | heavy work | 1 | 1 | 2 | 1.21 | 2 | 1 | 6 | 1.69 |
| | travel, sport | | | | | | | 1.5 | 1.21 |
| | total hours | 24 | | 24 | | 24 | | 24 | |

*C3.5.5.3. Occupancy and utilisation factors rates*

As indicated in Table C20, the amount of time spent in different activities is included in the Robinson (1996) database. This kind of information can be used to establish the amount of time spent in different parts of the ERB2A biosphere. The duration values are not adopted directly since those given by Robinson are quite specific.

Instead, values suitable for the five ERB2A exposure groups are taken to be:

| | | |
|---|---|---|
| occupational | 8 hours per day | 1/3 year per year |
| recreational | 4 hours per day | 1/6 year per year |
| domestic | 4 hours per day | 1/6 year per year |
| sleeping | 8 hours per day | 1/3 year per year |
| total | 24 hours per day | 1 year per year |

where the figures may be taken to be representative of annual averages of activity duration. For example, agricultural workers might spend more time working during the lighter summer months, but correspondingly less in the darker winter. Overall there is a balance. Alternatives may be implemented but uncertainty in these figures is likely to be much less than an order of magnitude.

*C3.5.5.4. Duration of activities in the ERB2A system by exposure group*

*EG1 – Livestock farmers (Table C21)*

This group is assumed to be producing milk and beef from cattle.

For each ‘month’ spent irrigating the pasture land there are twenty eight days at eight hours per day, giving a total of 224 hours. To make use of the occupancy factors discussed, this must be converted to an equivalent daily average. With 8766 hours per year, this corresponds to around 2.5% of the year in this activity. A daily equivalent of 0.1 hours per day is therefore adopted, allowing for a few months of this activity.

A similar figure is adopted for harvesting, given that the working day would be longer during harvest. It is also conservative to assume that members of the exposure group spend time on the potentially contaminated soil during this activity which is associated with high airborne dust concentrations.

For simplicity, farm work near water storage (during irrigation), plant processing (hay-making) and manuring are also assigned the same figure of 0.1 hours per day. An equivalent figure applies to farmyard work as to work in the fields and, in addition, one hour per day is assigned to each of animal husbandry, processing and storage and to milking. This leaves 'general farm work on irrigated land' to be determined by the overall assumption of an annual average of an eight hour working day.

A conservative assumption that agricultural land is used for recreational purposes is made. Partitioning of time between the four areas is assumed to be according to relative areas, as discussed in Annex CI to this Part.

Time in the domestic environment is split between five activities, two of which are associated with airborne aerosols. One hour per day is associated with showering and half an hour per day for cooking. Two poorly defined activities are included and these are arbitrarily assigned 0.1 hours per day on an annual basis – domestic activities using water and general domestic activities at high dust levels. The remaining time (general domestic activity at ambient dust levels) is calculated from these figures since there is an average of four hours per day in the domestic environment.

Sleeping is assumed to take place in the domestic environment at an average of 8 hours per day.

*EG2 – Arable farmers (Table C22)*

Farming practices differ between livestock and vegetable farmers. A value of 0.1 hours per day (annual equivalent) is assumed for each of plant burning – outdoors, ploughing/digging irrigated land, irrigating irrigated land, general farm work near water storage, plant processing and storage indoors, harvesting on irrigated land and manuring (indoors and outdoors). The remainder of the time is assumed spent in general farm work on irrigated land. However, within these categories of activity, time is split between the two crops according to the area of each under cultivation. Recreational domestic and sleeping activities are partitioned in a similar manner to the livestock farmer group, since there is no additional information to the contrary in the group descriptions.

*EG3 – Horticultural producers (Table C23)*

These differ from their EG2 counterparts only in the occupational activities on green vegetables and fruit soils. Recreational, domestic and sleeping durations are the same as for groups EG1 and EG2.

*EG4 – Villagers with kitchen garden (Table C24)*

This group is characterised by having occupational time in the village environment but recreational time is spent in the garden. A figure of 0.1 hours per day equivalent is adopted for watering the garden and the remainder of recreational time is accounted for in general ending of the garden. N.B., from Annex CI, it may be seen that, in order to be self sufficient in green and root vegetables, this group requires an area of just over 30 $m^2$. Irrigated farmland is not employed in recreational activities but domestic and sleeping activities are the same as for other exposure groups.

*EG5 – Villagers (Table C25)*

The occupancy of the different areas corresponds to defaults for the other groups. Occupational time is spent in the village while recreational time is spent on the agricultural land. Domestic and sleeping time is based on the same assumptions as for the other groups since there has been no identified behaviour for which these activities and locations have been identified as being of particular interest.

TABLE C21. ACTIVITY DURATION AND LOCATION FOR THE EG1 **LIVESTOCK FARMER GROUP** IN THE ERB2A BIOSPHERE. VALUES GIVEN ARE IN HOURS PER DAY, AVERAGED OVER THE YEAR

| ***EG1 - Livestock farmers*** | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village |
|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | |
| plant burning - outdoors | | | | | | | | | | |
| ploughing/digging irrigated land | | | | | | | | | | |
| irrigating irrigated land | 0.1 | | | | | | | | | |
| general farm work near water storage | 0.1 | | | | | | | | | |
| General farm work on irrigated land | 5.4 | | | | | | | | | |
| Plant processing and storage indoors | 0.1 | | | | | | | | | |
| animal husbandry, processing and storage | | | | | | | 1 | | | |
| Harvesting on irrigated land | 0.1 | | | | | | | | | |
| milking indoors | | | | | | | 1 | | | |
| Manuring (indoors and outdoors) | 0.1 | | | | | | 0.1 | | | |
| general occupation | | | | | | | | | | |
| *Recreational* | | | | | | | | | | |
| Out-door activities on irrigated land | 3.37 | 0.06 | 0.45 | 0.05 | 0.08 | | | | | |
| outdoor digging (gardening) | | | | | | | | | | |
| Watering the garden | | | | | | | | | | |
| *Domestic* | | | | | | | | | | |
| General domestic act. (ambient dust levels) | | | | | | | | | 2.3 | |
| General domestic act. (high dust levels) | | | | | | | | | 0.1 | |
| Domestic showering /bathing/sauna | | | | | | 1 | | | | |
| cooking | | | | | | | | | 0.5 | |
| domestic activities using water | | | | | | 0.1 | | | | |
| *Sleeping* | | | | | | | | | 8 | |

TABLE C22. ACTIVITY DURATION AND LOCATION FOR THE EG2 **ARABLE FARMER GROUP** IN THE ERB2A BIOSPHERE. VALUES GIVEN ARE HOURS PER DAY, AVERAGED OVER THE YEAR

| ***EG2 - Arable farmers*** | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | | totals |
| plant burning – outdoors | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| ploughing/digging irrigated land | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| irrigating irrigated land | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| general farm work near water storage | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| general farm work on irrigated land | | $8.15\times10^{-1}$ | 6.48 | | | | | | | | 7.3 |
| plant processing and storage indoors | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| animal husbandry, processing and storage | | | | | | | | | | | |
| harvesting on irrigated land | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| milking indoors | | | | | | | | | | | |
| manuring (indoors and outdoors) | | $1.12\times10^{-2}$ | $8.88\times10^{-2}$ | | | | | | | | 0.1 |
| general occupation | | | | | | | | | | | |
| *Recreational* | | | | | | | | | | | |
| out-door activities on irrigated land | 3.37 | 0.06 | 0.45 | 0.05 | 0.08 | | | | | | |
| outdoor digging (gardening) | | | | | | | | | | | |
| watering the garden | | | | | | | | | | | |
| *Domestic* | | | | | | | | | | | |
| general domestic act. (ambient dust levels) | | | | | | | | | 2.3 | | |
| general domestic act. (high dust levels) | | | | | | | | | 0.1 | | |
| domestic showering /bathing/sauna | | | | | | 1 | | | | | |
| cooking | | | | | | | | | 0.5 | | |
| domestic activities using water | | | | | | 0.1 | | | | | |
| *Sleeping* | | | | | | | | | 8 | | |

TABLE C23. ACTIVITY DURATION AND LOCATION FOR THE EG3 **HORTICULTURAL PRODUCER GROUP** IN THE ERB2A BIOSPHERE. VALUES GIVEN ARE HOURS PER DAY, AVERAGED OVER THE YEAR

| ***EG3 – Horticultural producers*** | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | | totals |
| plant burning – outdoors | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| ploughing/digging irrigated land | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| irrigating irrigated land | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| general farm work near water storage | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| general farm work on irrigated land | | | | 4.29E+00 | 3.01E+00 | | | | | | 7.3 |
| plant processing and storage indoors | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| animal husbandry, processing and storage | | | | | | | | | | | |
| harvesting on irrigated land | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| milking indoors | | | | | | | | | | | |
| manuring (indoors and outdoors) | | | | $5.88\times10^{-2}$ | $4.12\times10^{-2}$ | | | | | | 0.1 |
| general occupation | | | | | | | | | | | |
| *Recreational* | | | | | | | | | | | |
| out-door activities on irrigated land | 3.37 | 0.06 | 0.45 | 0.05 | 0.08 | | | | | | |
| outdoor digging (gardening) | | | | | | | | | | | |
| watering the garden | | | | | | | | | | | |
| *Domestic* | | | | | | | | | | | |
| general domestic act. (ambient dust levels) | | | | | | | | | 2.3 | | |
| general domestic act. (high dust levels) | | | | | | | | | 0.1 | | |
| domestic showering /bathing/sauna | | | | | | 1 | | | | | |
| cooking | | | | | | | | | 0.5 | | |
| domestic activities using water | | | | | | 0.1 | | | | | |
| *Sleeping* | | | | | | | | | 8 | | |

TABLE C24. ACTIVITY DURATION AND LOCATION FOR THE EG4 **VILLAGER WITH KITCHEN GARDEN GROUP** IN THE ERB2A BIOSPHERE. VALUES GIVEN ARE HOURS PER DAY, AVERAGED OVER THE YEAR

| ***EG4 – Villagers with kitchen gardens*** | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village |
|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | |
| plant burning - outdoors | | | | | | | | | | |
| ploughing/digging irrigated land | | | | | | | | | | |
| irrigating irrigated land | | | | | | | | | | |
| general farm work near water storage | | | | | | | | | | |
| general farm work on irrigated land | | | | | | | | | | |
| plant processing and storage indoors | | | | | | | | | | |
| animal husbandry, processing and storage | | | | | | | | | | |
| harvesting on irrigated land | | | | | | | | | | |
| milking indoors | | | | | | | | | | |
| manuring (indoors and outdoors) | | | | | | | | | | |
| general occupation | | | | | | | | | | 8 |
| *Recreational* | | | | | | | | | | |
| out-door activities on irrigated land | | | | | | | | | | |
| outdoor digging (gardening) | | | | | | | | 3.9 | | |
| watering the garden | | | | | | | | 0.1 | | |
| *Domestic* | | | | | | | | | | |
| general domestic act. (ambient dust levels) | | | | | | | | | 2.3 | |
| general domestic act. (high dust levels) | | | | | | | | | 0.1 | |
| domestic showering /bathing/sauna | | | | | | 1 | | | | |
| cooking | | | | | | | | | 0.5 | |
| domestic activities using water | | | | | | 0.1 | | | | |
| *Sleeping* | | | | | | | | | 8 | |

TABLE C25. ACTIVITY DURATION AND LOCATION FOR THE EG5 **VILLAGER GARDEN GROUP** IN THE ERB2A BIOSPHERE. VALUES GIVEN ARE HOURS PER DAY, AVERAGED OVER THE YEAR

| *EG5 - Villagers* | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village |
|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | |
| plant burning - outdoors | | | | | | | | | | |
| ploughing/digging irrigated land | | | | | | | | | | |
| irrigating irrigated land | | | | | | | | | | |
| general farm work near water storage | | | | | | | | | | |
| general farm work on irrigated land | | | | | | | | | | |
| plant processing and storage indoors | | | | | | | | | | |
| animal husbandry, processing and storage | | | | | | | | | | |
| harvesting on irrigated land | | | | | | | | | | |
| milking indoors | | | | | | | | | | |
| manuring (indoors and outdoors) | | | | | | | | | | |
| general occupation | | | | | | | | | | 8 |
| *Recreational* | | | | | | | | | | |
| out-door activities on irrigated land | 3.37 | 0.06 | 0.45 | 0.05 | 0.08 | | | | | |
| outdoor digging (gardening) | | | | | | | | | | |
| watering the garden | | | | | | | | | | |
| *Domestic* | | | | | | | | | | |
| general domestic act. (ambient dust levels) | | | | | | | | | 2.3 | |
| general domestic act. (high dust levels) | | | | | | | | | 0.1 | |
| domestic showering /bathing/sauna | | | | | | 1 | | | | |
| cooking | | | | | | | | | 0.5 | |
| domestic activities using water | | | | | | 0.1 | | | | |
| *Sleeping* | | | | | | | | | 8 | |

*EG6 – Infants (Table C26)*

Robinson (1996) also provides a review of activities and durations for children groups in different age ranges. For one year old children the breakdown is:

| | |
|---|---|
| sleeping | 14 hours per day |
| domestic | 5 hours per day |
| outdoors | 1 hour per day |
| other (elsewhere) | 4 hours per day |

On this basis, it is here assumed that the *other* category may be taken to be in a similar environment to the domestic so that the fractional time balance for the "Infants" group is

| | |
|---|---|
| occupational | 0 years per year |
| recreational (playing) | 1/24 = 0.042 years per year |
| domestic | 9/24 = 0.375 years per year |
| sleeping | 14/24 = 0.58 |

These figures, combined with Table C11 may be used to derive the fractional occupancy factors for the different areas in the modelled area. The results are shown in Table C26. A further assumption is made for the "Infants" group, wherein it is assumed that in domestic activities, half an hour per day is spent in bathing with the remaining 8.5 hours in general childhood activities.

## C3.6. PROVISION OF DATA

Element independent data are provided in Table C27, and data for Nb-94, I-129, Tc-99, Np-237 and Nb-94 in Tables C28–C31 respectively. Single values of parameters to be used in calculations are provided, with references. This approach relies upon justifying the selection of parameters from previous modelling experience coupled with side calculations rather than to early recourse to extensive elicitation exercises. It is difficult to identify critical but uncertain parameters unless a real source term to the biosphere is available. However, several examples of potentially important data deficiencies are identified below. These issues arose from the application of the data protocol to ERB2A: see Annex CII to this Part.

As an alternative to cows, sheep could be considered, especially since sheep have a high transfer factor to milk for I-129. In this case, the fodder consumption rate would be lower by about an order of magnitude, whereas the transfer factor would be about 100 times larger.

There is considerable uncertainty about Tc residence time in soil and its availability for root uptake. Table C30 gives assumed data for root uptake somewhat below the peak reported values. A higher value could be considered as an alternative, but it may be appropriate to correlate this with a lower soil residence time, see Annex CIII to this Part. There are also uncertainties about the soil residence time for other radionuclides. ERB2A assumptions take account of the likely organic content of the soil and information in Kocher (1991) and Bunzl et al., (1995).

Alternative assumptions concerning weathering of activity from irrigated crops, activity concentrations in suspended soil, and the relative significance of losses due to erosion and cropping are considered in Annex CIII to this Part.

TABLE C26. **FRACTIONAL OCCUPANCY** FACTORS FOR THE “INFANTS” GROUP

| ***EG1 - Livestock farmers*** | livestock / livestock soils | root crop soils | cereal soils | green veg. soils | fruit soils | irrigation / water sources | farm yard environment | garden soils | domestic environment | village |
|---|---|---|---|---|---|---|---|---|---|---|
| *Occupational* | | | | | | | | | | |
| plant burning - outdoors | | | | | | | | | | |
| ploughing/digging irrigated land | | | | | | | | | | |
| irrigating irrigated land | | | | | | | | | | |
| general farm work near water storage | | | | | | | | | | |
| general farm work on irrigated land | | | | | | | | | | |
| plant processing and storage indoors | | | | | | | | | | |
| animal husbandry, processing and storage | | | | | | | | | | |
| Harvesting on irrigated land | | | | | | | | | | |
| milking indoors | | | | | | | | | | |
| Manuring (indoors and outdoors) | | | | | | | | | | |
| general occupation | | | | | | | | | | |
| *Recreational* | | | | | | | | | | |
| out-door activities on irrigated land | | | | | | | | 0.0417 | | |
| outdoor digging (gardening) | | | | | | | | | | |
| watering the garden | | | | | | | | | | |
| *Domestic* | | | | | | | | | | |
| general domestic act. (ambient dust levels) | | | | | | | | | 0.354 | |
| general domestic act. (high dust levels) | | | | | | | | | | |
| domestic showering /bathing/sauna | | | | | | | | | 0.0208 | |
| cooking | | | | | | | | | | |
| domestic activities using water | | | | | | | | | | |
| *Sleeping* | | | | | | | | | 0.583 | |

TABLE C27. ELEMENT INDEPENDENT DATA

| Parameter | Value | Units | Indicative Range[1] Lower | Upper | Justification and Comments – references are at end of table |
|---|---|---|---|---|---|
| Irrigation rate, $V_{irr}$ | 2.0E-1 | $m^3 y^{-1}$ | 0.1 | 0.4 | Ranges are relatively narrow |
| Infiltration rate, I | 1.0E-1 | $m y^{-1}$ | 0.05 | 0.2 | |
| Wet soil porosity, θ | 2.0E-1 | – | 0.15 | 0.25 | |
| Total soil porosity, $\theta_t$ | 5.0E-1 | – | 0.3 | 0.5 | |
| Cultivated soil thickness, d | 3.0E-1 | M | 0.1 | 0.3 | |
| Soil grain density, ρ | 2.65E3 | $kg m^{-3}$ | 2000 | 3000 | |
| Water ingestion rate humans, $ING_w$ | 1.2E0 | $M^3 y^{-1}$ | | | BIOMASS ERB1 Working Document |
| Crop ingestion rate human, $ING_{crop}$ | | $kg y^{-1}$ | | | BIOMASS (2001) |
| – Root veg | 3.2E2 | | | | |
| – Green veg | 2.9E2 | | | | |
| – Grain | 4.7E2 | | | | |
| Crop soil contamination, $S_{crop}$ | | kg dw soil per kg fw crop | | | Chosen from consideration of data in BIOMOVS II (1996), Müller and Pröhl (1993), Ashton and Sumerling (1988), Smith et al., (1996) and Brown and Simmonds (1995) |
| – Root veg | 2.0E-4 | | 2.0E-4 | 2E-3 | |
| – Green veg | 2.0E-4 | | 2.0E-4 | 2E-3 | |
| – Grain | 2.0E-4 | | 2.0E-4 | 2E-3 | |
| – Pasture | 2.0E-3 | | 3E-4 | 2E-3 | |
| Crop annual yield, Y | | $kg fw y^{-1}$ | | | Chosen from consideration of data in BIOMOVS II (1996), Müller and Pröhl (1993), Ashton and Sumerling (1988), Smith et al., (1996) and Brown and Simmonds (1995) |
| – Root veg | 3.0E0 | | | | |
| – Green veg | 3.0E0 | | | | |
| – Grain | 4.0E-1 | | | | |
| – Pasture, $Y_{past}$ | 5.0E0 | | | | |
| Standing yield of pasture, $SB_{past}$ | 8.3E-1 | kg | | | Assumes the annual yield is grazed six times |
| Animal product consumption rate, $ING_{prod}$ | | $kg y^{-1}$ | | | BIOMASS (2001) |
| – Meat | 2.1E2 | | | | |
| – Offal | 1.4E1 | | | | |
| – Milk | 7.4E2 | | | | |
| Animal consumption rate, fodder $ING_{fodd}$ | 7.0E1 | $kg d^{-1}$ fw | | | Based on dairy cattle, and IAEA (1994) |
| Animal water consumption rate, $ING_{wa}$ | 7.0E-2 | $m^3 d^{-1}$ | | | Based on dairy cattle, and IAEA (1994) |

[1]Indicative range considered relevant to ERB2A assessment context and system description provided for some cases only.

TABLE C27. ELEMENT INDEPENDENT DATA (CONTINUED)

| Parameter | Value | Units | Indicative Range[1] Lower | Upper | Justification and Comments – references are at end of table |
|---|---|---|---|---|---|
| Animal soil consumption rate, $ING_{sa}$ | 6.0E-1 | kg $d^{-1}$ wet soil | | | Based on dairy cattle, and IAEA (1994) |
| Water density, $\rho_w$ | 1.0E3 | kg $m^{-3}$ | | | Lide (2000) |
| Animal breathing rate, $BR_a$ | 5.4E0 | $m^3$ $h^{-1}$ | | | Brown and Simmonds (1995) |
| Animal occupancy, $O_{an}$ | 2.4E1 | h $d^{-1}$ | | | |
| Dust in air, $dust_s$<br>– value for normal activity<br>– value for physical working in dry soil conditions | <br>1.0E-7<br>5.0E-6 | kg $m^{-3}$ | | | BIOMOVS (1990) |
| Number of animals in area of interest, SD | 2.0E-4 | – | | | BIOMOVS II (1996), Klos et al., (1993) |
| Inadvertant soil consumption, human, $ING_{soil}$ (adults) | 8.3E-3 | kg $y^{-1}$ fw | | | BIOMASS (2001) |
| Soil occupancy, human $O_s$<br>– value for normal activity<br>– value for hard physical activity in dry soil conditions | <br>4.0E3<br>4.5E2 | h $y^{-1}$ | | | BIOMASS (2001)<br>Note that soil occupancy does not include domestic and sleeping occupancy. |
| Bathing occupancy, $O_{wout}$ | 3.65E2 | h $y^{-1}$ | | | BIOMASS (2001) |
| Human Adult Breathing rate, BR<br>– value for normal activity<br>– value for physical working in dry soil conditions | <br>1.2E0<br>1.7E0 | $m^3$ $h^{-1}$ | | | BIOMASS (2000) |
| Human Infant Breathing Rate | 2.2E-1 | $m^3$ $h^{-1}$ | | | BIOMASS (2000) |
| Concentration of aerosol, $AIR_{aero}$ | 1.0E-11 | $m^3$ $m^{-3}$ | | | Derived from Lawson and Smith (1984) |
| Occupancy for breathing aerosol, $O_{aero}$ | 3.65E1 | h $y^{-1}$ | | | BIOMASS (2001) |
| Time from irrigation to harvest, T<br>– Root veg<br>– Green veg<br>– Grain<br>– Pasture | <br>4.0E-2<br>2.0E-2<br>7.5E-2<br>2.0E-2 | y | | | Typical farming practice as suggested by personal communication from Pröhl and Coughrey. |

[1]Indicative range considered relevant to ERB2A assessment context and system description provided for some cases only.

TABLE C27. REFERENCES

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# TABLE C28. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, I-129

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Concentration in well, $C_w$ | 1.0E0 | Bq $m^{-3}$ | Prescribed in assessment context |
| Decay constant, $\lambda$ | 4.4E-8 | $y^{-1}$ | ICRP (1983) |
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.1E-7 | | IAEA (1996) |
| – Child | 1.8E-7 | | IAEA (1996) – <1 year |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 3.6E-8 | | IAEA (1996) |
| – Child | 7.2E-8 | | IAEA (1996) – <1 year |
| External irradiation rate, $DC_{exts}$ | 2.5E-16 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| External dose factor, water immersion, $DC_{imw}$ | 3.2E-15 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| Sorption coefficient soil, $K_d$ | 1.0E-2 | $m^3$ $kg^{-1}$ | IAEA (1994). Data for R are more relevant here, so $K_d$ chosen to give residence time of about 200 y. |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ fw per Bq $kg^{-1}$ dry soil | |
| – Root veg | 3.0E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000) |
| – Green veg | 3.0E-3 | | |
| – Grain | 3.0E-3 | | |
| – Pasture | 3.0E-3 | | |
| Interception factor for crop, $I_{crop}$ | 3.0E-1 | | Pröhl and Müller (1996) |
| External contamination due to interception, food processing retained fraction, $F_{p3}$ | | – | |
| – Root veg | 0.0E0 | | No deposition to root surface |
| – Green veg | 1.0E-1 | | Smith et al., (1988) |
| – Grain | 1.0E-2 | | Only a small fraction of total intercepted falls on ears |
| Internal food processing retained fraction, $F_{p2}$ | 1.0E0 | – | NRPB guidance in Green and Wilkins (1995), cautious but not very. |
| External contamination due to soil, food processing retained fraction, $F_{p1}$ | | | |
| – Root veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Green veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Grain | 1.0E-1 | | Green and Wilkins (1995) |
| Absorbed fraction, external to internal, $F_{abs}$ | 5.0E-1 | – | Evidence from farming additive practice |

TABLE C28. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, I-129 (CONTINUED)

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Translocation factor, $F_{trans}$ | | – | |
| – Root veg | 1.0E-1 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Green veg | 1.0E0 | | Activity already at location |
| – Grain | 1.0E-1 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Pasture | 1.0E0 | | Activity already at location |
| Weathering rate, W | | $y^{-1}$ | |
| – Root veg | 1.8E1 | | |
| – Green veg | 1.8E1 | | From consideration of Brown and Simmonds (1995) and Müller and Pröhl (1993) |
| – Grain | 1.8E1 | | |
| – Pasture | 1.8E1 | | |
| Animal product transfer factor from ingestion, Tfproding | | d $kg^{-1}$ | |
| – Meat | 3.0E-3 | | Smith et al., (1996) Cows. |
| – Offal | 3.0E-3 | | NRPB (1996) – used in calculating Generalised Derived Limits |
| – Milk | 3.0E-3 | | Smith et al., (1996). Consider separate calculation for iodine and milk from goats/sheep |
| Fraction of ingested activity reaching the body fluid of man, $f(ing)_M$ | 1.0E0 | | ICRP (1996) |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 5.0E-1 | – | Coughtrey et al., (1983) – inhalation class D, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 1.6E-1 | – | Coughtrey et al., (1983) – inhalation class D, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1(inh)$ | 1.0E0 | – | ICRP (1996) – inhalation class F |

## TABLE C28. REFERENCES

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TABLE C29. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Tc-99

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Concentration in well, $C_w$ | 1.0E0 | Bq $m^{-3}$ | Prescribed |
| Decay constant, $\lambda$ | 3.3E-6 | $y^{-1}$ | ICRP (1983) – well characterised |
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 6.4E-10 | | IAEA (1996) |
| – Child | 1.0E-8 | | |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.3E-8 | | IAEA (1996) |
| – Child | 4.1E-8 | | IAEA (1996) |
| External irradiation rate, $DC_{exts}$ | 2.4E-18 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| External dose factor, water immersion, $DC_{imw}$ | 1.1E-17 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| Sorption coefficient soil, $K_d$ | 1.7E-5 | $m^3$ $kg^{-1}$ | Sufficient to make Tc-99 mobile, i.e a soil half life approximately the same as that of the water, side calculations were undertaken comparing the results with those achieved with an immobile form of Tc-99 (see the Appendix A) |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ fw per Bq $kg^{-1}$ dry soil | |
| – Root veg | 1.0E1 | | From consideration of IAEA (1994) |
| – Green veg | 1.0E1 | | |
| – Grain | 1.0E1 | | |
| – Pasture | 1.0E1 | | |
| Interception factor for crop, $I_{crop}$ | 1.0E-1 | | Pröhl and Müller (1996) |
| External food processing retained fraction, $F_{p3}$ | | – | |
| – Root veg | 0.0E0 | | No deposition to root surface |
| – Green veg | 1.0E-1 | | Smith et al., (1988) |
| – Grain | 1.0E-2 | | Only a small fraction of total intercepted falls on ears |
| Internal food processing retained fraction, $F_{p2}$ | 1.0E0 | – | NRPB guidance in Green and Wilkins (1995), cautious but not very. |
| External contamination due to soil, food processing retained fraction, $F_{p1}$ | | | |
| – Root veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Green veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Grain | 1.0E-1 | | Green and Wilkins (1995) |
| Absorbed fraction, external to internal, $F_{abs}$ | 5.0E-1 | – | Evidence from farming additive practice |

TABLE C29. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Tc-99 (CONTINUED)

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Translocation factor, $F_{trans}$ | | – | |
| – Root veg | 1.0E-1 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Green veg | 1.0E0 | | Already located |
| – Grain | 1.0E-1 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Pasture | 1.0E0 | | Already located |
| Weathering rate, W | | $y^{-1}$ | |
| – Root veg | 1.8E1 | | From consideration of Brown and Simmonds (1995) and Müller and Pröhl (1993) |
| – Green veg | 1.8E1 | | |
| – Grain | 1.8E1 | | |
| – Pasture | 1.8E1 | | |
| Animal product transfer factor, Tfproding | | d $kg^{-1}$ | |
| – Meat | 6.0E-3 | | Smith et al., (1996) |
| – Offal | 2.1E-3 | | Smith et al., (1996) for cattle liver from consideration of ranges |
| – Milk | 7.5E-3 | | Smith et al., (1996) |
| Fraction of ingested activity reaching the body fluid of man, $f(ing)_M$ | 5.0E-1 | | ICRP (1996) |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1(inh)$ | 1.0E-1 | – | ICRP (1996) – inhalation class M |

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TABLE C30. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Np-237

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Concentration in well, $C_w$ | 1.0E0 | Bq m$^{-3}$ | Prescribed in assessment context |
| Decay constant, $\lambda$ | 3.2E-7 | y$^{-1}$ | ICRP (1983) |
| Ingestion dose coefficient, $DC_{ing}$ | | Sv Bq$^{-1}$ | |
| – Adult | 1.1E-7 | | IAEA (1996) |
| – Child | 2.0E-6 | | IAEA (1996) |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv Bq$^{-1}$ | |
| – Adult | 5.0E-5 | | IAEA (1996) |
| – Child | 9.8E-5 | | IAEA (1996) |
| External irradiation rate, $DC_{exts}$ | 1.5E-15 | Sv h$^{-1}$/Bq m$^{-3}$ | Eckerman and Ryman (1993) |
| External dose factor, water immersion, $DC_{imw}$ | 8.4E-15 | Sv h$^{-1}$/Bq m$^{-3}$ | Eckerman and Ryman (1993) |
| Sorption coefficient soil, $K_d$ | 3.0E-2 | m$^3$ kg$^{-1}$ | Coughtrey et al., (1983) |
| Crop concentration factor, $CF_{crop}$ | | Bq kg$^{-1}$ fw per Bq kg$^{-1}$ dry soil | |
| – Root veg | 5.0E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000) |
| – Green veg | 5.0E-3 | | |
| – Grain | 2.0E-3 | | |
| – Pasture | 5.0E-3 | | |
| Interception factor for crop, $I_{crop}$ | 5.0E-1 | | Pröhl and Müller (1996) |
| External food processing loss fraction, $F_{p3}$ | | – | |
| – Root veg | 0.0E0 | | No deposition to root surface |
| – Green veg | 1.0E-1 | | Smith et al., (1988) |
| – Grain | 1.0E-2 | | Only a small fraction of total intercepted falls on ears |
| Internal food processing retained fraction, $F_{p2}$ | 1.0E0 | – | NRPB guidance in Green and Wilkins (1995), cautious but not very. |
| External contamination due to soil, food processing retained fraction, $F_{p1}$ | | | |
| – Root veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Green veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Grain | 1.0E-1 | | Green and Wilkins (1995) |
| Absorbed fraction, external to internal, $F_{abs}$ | 5.0E-1 | - | Evidence from farming additive practice |
| Translocation factor, $F_{trans}$ | | - | |
| – Root veg | 0.0E0 | | Simmonds and Crick (1982) |
| – Green veg | 1.0E0 | | Activity already at location |
| – Grain | 1.0E-2 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Pasture | 1.0E0 | | No data available – assumed same as green veg |

TABLE C30. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Np-237 (CONTINUED)

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Weathering rate, W | | $y^{-1}$ | |
| – Root veg | 1.8E1 | | |
| – Green veg | 1.8E1 | | From consideration of Brown and Simmonds (1995) and Müller and Pröhl (1993) |
| – Grain | 1.8E1 | | |
| – Pasture | 1.8E1 | | |
| Animal transfer factor, TFproding | | | |
| – Meat | 1.0E-4 | $d\ l^{-1}$ | Smith et al., (1996) |
| – Offal | 1.0E-4 | $d\ l^{-1}$ | Smith et al., (1996) from consideration of range |
| – Milk | 1.0E-4 | | Smith et al., (1996) from consideration of range |
| Fraction of ingested activity reaching the body fluid of man, $f(ing)_M$ | 5.0E-4 | | ICRP (1996) |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | - | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | - | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1(inh)$ | 5.0E-4 | - | ICRP (1996) – inhalation class M |

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TABLE C31. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Nb-94

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Concentration in well, $C_w$ | 1.0E0 | Bq $m^{-3}$ | Prescribed in assessment context |
| Decay constant, $\lambda$ | 3.41E-5 | $y^{-1}$ | ICRP (1983) |
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.7E-9 | | IAEA (1996) |
| – Child | 1.5E-8 | | IAEA (1996) |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 9.9E-8 | | IAEA (1996) |
| – Child | 1.2E-7 | | IAEA (1996) |
| External irradiation rate, $DC_{exts}$ | 1.9E-13 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| External dose factor, water immersion, $DC_{imw}$ | 6.0E-13 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993) |
| Sorption coefficient soil, $K_d$ | 9.0E-1 | $m^3$ $kg^{-1}$ | from consideration of IAEA (1994) |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ fw per Bq $kg^{-1}$ dry soil | |
| – Root veg | 2.5E-3 | | Derived from Coughtrey et al., (1983) |
| – Green veg | 4.0E-4 | | |
| – Grain | 1.6E-3 | | |
| – Pasture | 4.0E-4 | | |
| Interception factor for crop, $I_{crop}$ | 5.0E-1 | | Pröhl and Müller (1996) |
| External contamination due to interception, food processing retained fraction, $F_{p3}$ | | – | |
| – Root veg | 0.0E0 | | No deposition to root surface |
| – Green veg | 1.0E-1 | | Smith et al., (1988) |
| – Grain | 1.0E-2 | | Only a small fraction of total intercepted falls on ears |
| Internal food processing retained fraction, $F_{p2}$ | 1.0E0 | – | NRPB guidance in Green and Wilkins (1995), cautious but not very. |
| External contamination due to soil, food processing retained fraction, $F_{p1}$ | | | |
| – Root veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Green veg | 1.0E-1 | | Green and Wilkins (1995) |
| – Grain | 1.0E-1 | | Green and Wilkins (1995) |
| Absorbed fraction, external to internal, $F_{abs}$ | 5.0E-1 | – | Evidence from farming additive practice |

TABLE C31. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Nb-94 (CONTINUED)

| Parameter | Value | Units | Justification – references are at end of table |
|---|---|---|---|
| Translocation factor, $F_{trans}$ | | – | |
| – Root veg | 0.0E0 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Green veg | 1.0E0 | | Activity already at location |
| – Grain | 1.0E-2 | | From consideration of Coughtrey et al., (1983) and Müller and Pröhl (1993) |
| – Pasture | 1.0E0 | | Activity already at location |
| Weathering rate, W | | $y^{-1}$ | |
| – Root veg | 1.8E1 | | |
| – Green veg | 1.8E1 | | From consideration of Brown and Simmonds (1995) and Müller and Pröhl (1993) |
| – Grain | 1.8E1 | | |
| – Pasture | 1.8E1 | | |
| Animal product transfer factor from ingestion, TFproding | | d $kg^{-1}$ | |
| – Meat | 1.7E-4 | | Ashton and Sumerling (1988) |
| – Offal | 2.1E-3 | | Ashton and Sumerling (1988) – for kidney used as higher than liver |
| – Milk | 4.0E-7 | | IAEA (1994) |
| Fraction of ingested activity reaching the body fluid of man, $f(ing)_M$ | 1.0E-2 | | ICRP (1996) |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1(inh)$ | 1.0E-2 | – | ICRP (1996) – inhalation class M |

## TABLE C31. REFERENCES


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Exposure group data are provided in Tables C32 and C33. These exposure group data combine the information for each exposure pathway for each exposure group in the Tables C20–C26.

TABLE C32. EXPOSURE GROUP CONSUMPTION DATA (kg $y^{-1}$ UNLESS STATED)

| Consumption Category | Exposure Group | | | | |
|---|---|---|---|---|---|
| | Arable | Livestock | Hort | Villager | Infant |
| Root vegetables | 3.2E2 | 1.1E2 | 3.2E2 | 1.1E2 | 5.2E1 |
| Green vegetables | 9.6E1 | 9.6E1 | 2.9E2 | 9.6E1 | 6.4E1 |
| Grain | 4.7E2 | 1.6E2 | 1.6E2 | 1.6E2 | 1.5E1 |
| Meat | 7.0E1 | 2.1E2 | 7.0E1 | 7.0E1 | 3.0E1 |
| Offal | 4.5E0 | 1.4E1 | 4.5E0 | 4.5E0 | 6.0E-1 |
| Milk | 2.5E2 | 7.4E2 | 2.5E2 | 2.5E2 | 5.3E1 |
| Soil | 8.3E-3 | 8.3E-3 | 3.7E-3 | 3.7E-3 | 3.7E-2 |
| Water ($m^3$ $y^{-1}$) | 1.2E0 | 1.2E0 | 1.2E0 | 6.0E-1 | 2.6E-1 |

TABLE C33. EXPOSURE GROUP OCCUPANCY DATA

| | Exposure Group | | | | |
|---|---|---|---|---|---|
| | Arable | Livestock | Hort | Villager | Infant |
| Normal breathing rate, normal dust level | 3.9E3 | 4.0E3 | 3.9E3 | 4.4E3 | 4.4E3 |
| High breathing rate, high dust level | 4.5E2 | 3.4E2 | 4.5E2 | 0.0E0 | 0.0E0 |
| Total occupancy | 4.4E3 | 4.4E3 | 4.4E3 | 4.4E3 | 4.4E3 |

## C3.7. RESULTS FOR ERB2A

Tables C34–C37 give results for unit exposure via each pathway, based on calculations made by ANDRA, CIEMAT, Jozef Stefan Institute, and QuantiSci. Annual doses are also given based on ‘a priori’ assumptions about consumption rates, etc. The results from three of these organisations were made using the same code and the fourth group used different software. In getting to one consistent set of results, a number of corrections and clarifications were made to the draft calculation specifications, as recorded in the Working Material. The consistency achieved in the results gives confidence that conceptual and mathematical model descriptions were being interpreted coherently. This approach to confirming that the models can be understood by others, by having more than one group interpreting the model description, was an important recommendation by BIOMOVS II (1996a). Implications of alternative interpretations have been quantitatively examined in Annex CIII.

Tables C38–C41 give the results for the ERB2A candidate critical groups. Details of the contributions via each pathway are also provided so that the relative significance of exposure pathways can be investigated. The application of these results to a realistic assessment source term is demonstrated in Annex CIV. These results can be used to determine the absolute significance of the different pathways, etc, but only in the context of that particular source term.

TABLE C34. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2A, I-129 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name, equation reference in | Dose to adult, Sv per unit exposure | Units of expsoure | Dose, Sv/y a priori consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|
| Consumption of drinking water | 1.10E-07 | Sv per m3 consumed | 1.32E-07 | n/a constant exposure |
| Consumptionof crops | | | | |
| – Root vegetables | 1.17E-10 | Sv per kg consumed | 3.74E-08 | Exceeded at 0y |
| – Green vegetables | 1.18E-09 | Sv per kg consumed | 3.43E-07 | Exceeded at 0y |
| – Grain | 8.53E-10 | Sv per kg consumed | 4.01E-07 | Exceeded at 0y |
| Consumption of animal (cow) products | | | | |
| – Meat | 9.81E-11 | Sv per kg consumed | 2.06E-08 | Exceeded at 0y |
| – Offal | 9.81E-11 | Sv per kg consumed | 1.37E-09 | Exceeded at 0y |
| – Milk | 9.81E-11 | Sv per litre consumed | 7.26E-08 | Exceeded at 0y |
| Consumption of soil (not on crops) | 1.94E-09 | Sv per kg consumed | 1.61E-11 | 98y |
| External irradiation from soil | 6.72E-15 | Sv per hour | 2.96E-11 | 98y |
| External irradiation, immersion in water | 3.20E-15 | Sv per hour | 1.17E-12 | n/a constant exposure |
| Inhalation of dust from soil | | | | |
| – Normal activity | 8.63E-17 | Sv per hour | 3.45E-13 | 98y |
| – Hard physical activity | 6.11E-15 | Sv per hour | 2.75E-12 | 98y |
| Inhalation of aerosols/spray | 4.32E-19 | Sv per hour | 1.58E-17 | n/a constant exposure |

TABLE C35. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2A, Tc-99 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose to adult, Sv per unit exposure | Units of expsoure | Dose, Sv/y a priori consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|
| Consumption of drinking water | 6.40E-10 | Sv per m3 consumed | 7.68E-10 | n/a constant exposure |
| Consumptionof crops | | | | |
| – Root vegetables | 2.26E-12 | Sv per kg consumed | 7.23E-10 | 2y |
| – Green vegetables | 4.33E-12 | Sv per kg consumed | 1.26E-09 | 1y |
| – Grain | 3.69E-12 | Sv per kg consumed | 1.73E-09 | 2y |
| Consumption of animal (cow) products | | | | |
| – Meat | 1.40E-12 | Sv per kg consumed | 2.94E-10 | 2y |
| – Offal | 4.90E-13 | Sv per kg consumed | 6.86E-12 | 2y |
| – Milk | 1.75E-12 | Sv per litre consumed | 1.30E-09 | 2y |
| Consumption of soil (not on crops) | 1.78E-13 | Sv per kg consumed | 1.48E-15 | 2y |
| External irradiation from soil | 1.02E-18 | Sv per hour | 4.49E-15 | 2y |
| External irradiation, immersion in water | 1.10E-17 | Sv per hour | 4.02E-15 | n/a constant exposure |
| Inhalation of dust from soil | | | | |
| – Normal activity | 5.06E-20 | Sv per hour | 2.02E-16 | 2y |
| – Hard physical activity | 3.59E-18 | Sv per hour | 1.62E-15 | 2y |
| Inhalation of aerosols/spray | 1.56E-19 | Sv per hour | 5.69E-18 | n/a constant exposure |

TABLE C36. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2A, Np-237 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose to adult, Sv per unit exposure | Units of expsoure | Dose, Sv/y a priori consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|
| Consumption of drinking water | 1.10E-07 | Sv per m3 consumed | 1.32E-07 | n/a constant exposure |
| Consumptionof crops | | | | |
| – Root vegetables | 3.31E-11 | Sv per kg consumed | 1.06E-08 | 277y |
| – Green vegetables | 1.99E-09 | Sv per kg consumed | 5.78E-07 | Exceeded at 0y |
| – Grain | 1.86E-10 | Sv per kg consumed | 8.76E-08 | Exceeded at 0y |
| Consumption of animal (cow) products | | | | |
| – Meat | 5.41E-12 | Sv per kg consumed | 1.14E-09 | 28y |
| – Offal | 5.41E-12 | Sv per kg consumed | 7.57E-11 | 28y |
| – Milk | 5.41E-12 | Sv per litre consumed | 4.00E-09 | 28y |
| Consumption of soil (not on crops) | 5.73E-09 | Sv per kg consumed | 4.76E-11 | 277y |
| External irradiation from soil | 1.19E-13 | Sv per hour | 5.25E-10 | 277y |
| External irradiation, immersion in water | 8.40E-15 | Sv per hour | 3.07E-12 | n/a constant exposure |
| Inhalation of dust from soil | | | | |
| – Normal activity | 3.58E-13 | Sv per hour | 1.43E-09 | 277y |
| – Hard physical activity | 2.54E-11 | Sv per hour | 1.14E-08 | 277y |
| Inhalation of aerosols/spray | 6.00E-16 | Sv per hour | 2.19E-14 | n/a constant exposure |

TABLE C37. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2A, Nb-94 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose to adult, Sv per unit exposure | Units of expsoure | Dose, Sv/y a priori consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|
| Consumption of drinking water | 1.70E-09 | Sv per m3 consumed | 2.04E-09 | n/a constant exposure |
| Consumptionof crops | | | | |
| – Root vegetables | 6.50E-12 | Sv per kg consumed | 2.08E-09 | 7230y |
| – Green vegetables | 3.14E-11 | Sv per kg consumed | 9.10E-09 | Exceeded at 0y |
| – Grain | 6.85E-12 | Sv per kg consumed | 3.22E-09 | 5480y |
| Consumption of animal (cow) products | | | | |
| – Meat | 4.65E-13 | Sv per kg consumed | 9.77E-11 | 6290y |
| – Offal | 5.74E-12 | Sv per kg consumed | 8.04E-11 | 6290y |
| – Milk | 1.09E-15 | Sv per litre consumed | 8.07E-13 | 6290y |
| Consumption of soil (not on crops) | 2.24E-09 | Sv per kg consumed | 1.86E-11 | 7230y |
| External irradiation from soil | 3.82E-10 | Sv per hour | 1.68E-06 | 7230y |
| External irradiation, immersion in water | 6.00E-13 | Sv per hour | 2.19E-10 | n/a constant exposure |
| Inhalation of dust from soil | | | | |
| – Normal activity | 1.80E-14 | Sv per hour | 7.21E-11 | 7230y |
| – Hard physical activity | 1.28E-12 | Sv per hour | 5.75E-10 | 7230y |
| Inhalation of aerosols/spray | 1.19E-18 | Sv per hour | 4.34E-17 | n/a constant exposure |

TABLE C38. I-129 EXPOSURE GROUP DOSES AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Livestock farmer | | Arable farmer | | Horticultural producer | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Drinking water | $m^3$/y | 1.2 | 1.3E-07 | 1.2 | 1.3E-07 | 1.2 | 1.3E-07 | 0.6 | 6.6E-08 | 0.26 | 4.7E-08 |
| Crop consumption | | | | | | | | | | | |
| – Root vegetables | kg/y | 110 | 1.3E-08 | 320 | 3.7E-08 | 320 | 3.7E-08 | 110 | 1.3E-08 | 52 | 9.9E-09 |
| – Green vegetables | kg/y | 96 | 1.1E-07 | 96 | 1.1E-07 | 290 | 3.4E-07 | 96 | 1.1E-07 | 64 | 1.2E-07 |
| – Grain | kg/y | 160 | 1.4E-07 | 470 | 4.0E-07 | 160 | 1.4E-07 | 160 | 1.4E-07 | 15 | 2.1E-08 |
| Animal product consumption | | | | | | | | | | | |
| – Meat | kg/y | 210 | 2.1E-08 | 70 | 6.9E-09 | 70 | 6.9E-09 | 70 | 6.9E-09 | 30 | 4.8E-09 |
| – Offal | kg/y | 14 | 1.4E-09 | 4.5 | 4.4E-10 | 4.5 | 4.4E-10 | 4.5 | 4.4E-10 | 0.6 | 9.6E-11 |
| – Milk | kg/y | 740 | 7.3E-08 | 250 | 2.5E-08 | 250 | 2.5E-08 | 250 | 2.5E-08 | 53 | 8.5E-09 |
| Soil consumption | kg/y | 0.0083 | 1.6E-11 | 0.0083 | 1.6E-11 | 0.0037 | 7.2E-12 | 0.0037 | 7.2E-12 | 0.037 | 1.2E-10 |
| External from soil | h/y | 4400 | 3.0E-11 | 4400 | 3.0E-11 | 4400 | 3.0E-11 | 4400 | 3.0E-11 | 4400 | 3.0E-11 |
| External, immersion in water | h/y | 365 | 1.2E-12 | 365 | 1.2E-12 | 365 | 1.2E-12 | 365 | 1.2E-12 | 365 | 1.2E-12 |
| Dust inhalation | | | | | | | | | | | |
| – Normal activity | h/y | 4000 | 3.5E-13 | 3900 | 3.4E-13 | 3900 | 3.4E-13 | 4400 | 3.8E-13 | 4400 | 1.4E-13 |
| – Hard physical activity | h/y | 340 | 2.1E-12 | 450 | 2.8E-12 | 450 | 2.8E-12 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Aerosol inhalation | h/y | 36.5 | 1.6E-17 | 36.5 | 1.6E-17 | 36.5 | 1.6E-17 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Total | | | 4.9E-07 | | 7.2E-07 | | 6.8E-07 | | 3.6E-07 | | 2.2E-07 |

TABLE C39. Tc-99 EXPOSURE GROUP DOSES AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Livestock farmer | | Arable farmer | | Horticultural producer | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Drinking water | $m^3/y$ | 1.2 | 7.7E-10 | 1.2 | 7.7E-10 | 1.2 | 7.7E-10 | 0.6 | 3.8E-10 | 0.26 | 2.6E-09 |
| Crop consumption | | | | | | | | | | | |
| – Root vegetables | kg/y | 110 | 2.5E-10 | 320 | 7.2E-10 | 320 | 7.2E-10 | 110 | 2.5E-10 | 52 | 1.8E-09 |
| – Green vegetables | kg/y | 96 | 4.2E-10 | 96 | 4.2E-10 | 290 | 1.3E-09 | 96 | 4.2E-10 | 64 | 4.3E-09 |
| – Grain | kg/y | 160 | 5.9E-10 | 470 | 1.7E-09 | 160 | 5.9E-10 | 160 | 5.9E-10 | 15 | 8.7E-10 |
| Animal product consumption | | | | | | | | | | | |
| – Meat | kg/y | 210 | 2.9E-10 | 70 | 9.8E-11 | 70 | 9.8E-11 | 70 | 9.8E-11 | 30 | 6.6E-10 |
| – Offal | kg/y | 14 | 6.9E-12 | 4.5 | 2.2E-12 | 4.5 | 2.2E-12 | 4.5 | 2.2E-12 | 0.6 | 4.6E-12 |
| – Milk | kg/y | 740 | 1.3E-09 | 250 | 4.4E-10 | 250 | 4.4E-10 | 250 | 4.4E-10 | 53 | 1.4E-09 |
| Soil consumption | kg/y | 0.0083 | 1.5E-15 | 0.0083 | 1.5E-15 | 0.0037 | 6.6E-16 | 0.0037 | 6.6E-16 | 0.037 | 1.0E-13 |
| External from soil | h/y | 4400 | 4.5E-15 | 4400 | 4.5E-15 | 4400 | 4.5E-15 | 4400 | 4.5E-15 | 4400 | 4.5E-15 |
| External, immersion in water | h/y | 365 | 4.0E-15 | 365 | 4.0E-15 | 365 | 4.0E-15 | 365 | 4.0E-15 | 365 | 4.0E-15 |
| Dust inhalation | | | | | | | | | | | |
| – Normal activity | h/y | 4000 | 2.0E-16 | 3900 | 2.0E-16 | 3900 | 2.0E-16 | 4400 | 2.2E-16 | 4400 | 1.3E-16 |
| – Hard physical activity | h/y | 340 | 1.2E-15 | 450 | 1.6E-15 | 450 | 1.6E-15 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Aerosol inhalation | h/y | 36.5 | 5.7E-18 | 36.5 | 5.7E-18 | 36.5 | 5.7E-18 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Total | | | 3.6E-09 | | 4.2E-09 | | 3.9E-09 | | 2.2E-09 | | 1.2E-08 |

TABLE C40. Np-237 EXPOSURE GROUP DOSES AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Livestock farmer | | Arable farmer | | Horticultural producer | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Drinking water | $m^3/y$ | 1.2 | 1.3E-07 | 1.2 | 1.3E-07 | 1.2 | 1.3E-07 | 0.6 | 6.6E-08 | 0.26 | 5.2E-07 |
| Crop consumption | | | | | | | | | | | |
| – Root vegetables | kg/y | 110 | 3.6E-09 | 320 | 1.1E-08 | 320 | 1.1E-08 | 110 | 3.6E-09 | 52 | 3.1E-08 |
| – Green vegetables | kg/y | 96 | 1.9E-07 | 96 | 1.9E-07 | 290 | 5.8E-07 | 96 | 1.9E-07 | 64 | 2.3E-06 |
| – Grain | kg/y | 160 | 3.0E-08 | 470 | 8.8E-08 | 160 | 3.0E-08 | 160 | 3.0E-08 | 15 | 5.1E-08 |
| Animal product consumption | | | | | | | | | | | |
| – Meat | kg/y | 210 | 1.1E-09 | 70 | 3.8E-10 | 70 | 3.8E-10 | 70 | 3.8E-10 | 30 | 2.9E-09 |
| – Offal | kg/y | 14 | 7.6E-11 | 4.5 | 2.4E-11 | 4.5 | 2.4E-11 | 4.5 | 2.4E-11 | 0.6 | 5.9E-11 |
| – Milk | kg/y | 740 | 4.0E-09 | 250 | 1.4E-09 | 250 | 1.4E-09 | 250 | 1.4E-09 | 53 | 5.2E-09 |
| Soil consumption | kg/y | 0.0083 | 4.8E-11 | 0.0083 | 4.8E-11 | 0.0037 | 2.1E-11 | 0.0037 | 2.1E-11 | 0.037 | 3.8E-09 |
| External from soil | h/y | 4400 | 5.2E-10 | 4400 | 5.2E-10 | 4400 | 5.2E-10 | 4400 | 5.2E-10 | 4400 | 5.2E-10 |
| External, immersion in water | h/y | 365 | 3.1E-12 | 365 | 3.1E-12 | 365 | 3.1E-12 | 365 | 3.1E-12 | 365 | 3.1E-12 |
| Dust inhalation | | | | | | | | | | | |
| – Normal activity | h/y | 4000 | 1.4E-09 | 3900 | 1.4E-09 | 3900 | 1.4E-09 | 4400 | 1.6E-09 | 4400 | 5.7E-10 |
| – Hard physical activity | h/y | 340 | 8.6E-09 | 450 | 1.1E-08 | 450 | 1.1E-08 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Aerosol inhalation | h/y | 36.5 | 2.2E-14 | 36.5 | 2.2E-14 | 36.5 | 2.2E-14 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Total | | | 3.7E-07 | | 4.4E-07 | | 7.7E-07 | | 2.9E-07 | | 2.9E-06 |

TABLE C41. Nb-94 EXPOSURE GROUP DOSES AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Livestock farmer | | Arable farmer | | Horticultural producer | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Drinking water | $m^3/y$ | 1.2 | 2.0E-09 | 1.2 | 2.0E-09 | 1.2 | 2.0E-09 | 0.6 | 1.0E-09 | 0.26 | 3.9E-09 |
| Crop consumption | | | | | | | | | | | |
| – Root vegetables | kg/y | 110 | 7.2E-10 | 320 | 2.1E-09 | 320 | 2.1E-09 | 110 | 7.2E-10 | 52 | 3.0E-09 |
| – Green vegetables | kg/y | 96 | 3.0E-09 | 96 | 3.0E-09 | 290 | 9.1E-09 | 96 | 3.0E-09 | 64 | 1.8E-08 |
| – Grain | kg/y | 160 | 1.1E-09 | 470 | 3.2E-09 | 160 | 1.1E-09 | 160 | 1.1E-09 | 15 | 9.1E-10 |
| Animal product consumption | | | | | | | | | | | |
| – Meat | kg/y | 210 | 9.8E-11 | 70 | 3.3E-11 | 70 | 3.3E-11 | 70 | 3.3E-11 | 30 | 1.2E-10 |
| – Offal | kg/y | 14 | 8.0E-11 | 4.5 | 2.6E-11 | 4.5 | 2.6E-11 | 4.5 | 2.6E-11 | 0.6 | 3.0E-11 |
| – Milk | kg/y | 740 | 8.1E-13 | 250 | 2.7E-13 | 250 | 2.7E-13 | 250 | 2.7E-13 | 53 | 5.1E-13 |
| Soil consumption | kg/y | 0.0083 | 1.9E-11 | 0.0083 | 1.9E-11 | 0.0037 | 8.3E-12 | 0.0037 | 8.3E-12 | 0.037 | 7.3E-10 |
| External from soil | h/y | 4400 | 1.7E-06 | 4400 | 1.7E-06 | 4400 | 1.7E-06 | 4400 | 1.7E-06 | 4400 | 1.7E-06 |
| External, immersion in water | h/y | 365 | 2.2E-10 | 365 | 2.2E-10 | 365 | 2.2E-10 | 365 | 2.2E-10 | 365 | 2.2E-10 |
| Dust inhalation | | | | | | | | | | | |
| – Normal activity | h/y | 4000 | 7.2E-11 | 3900 | 7.0E-11 | 3900 | 7.0E-11 | 4400 | 7.9E-11 | 4400 | 1.8E-11 |
| – Hard physical activity | h/y | 340 | 4.3E-10 | 450 | 5.7E-10 | 450 | 5.7E-10 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Aerosol inhalation | h/y | 36.5 | 4.3E-17 | 36.5 | 4.3E-17 | 36.5 | 4.3E-17 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Total | | | 1.7E-06 | | 1.7E-06 | | 1.7E-06 | | 1.7E-06 | | 1.7E-06 |

# C4. EXAMPLE REFERENCE BIOSPHERE 2B, NATURAL RELEASE OF CONTAMINATED GROUNDWATER TO THE SURFACE ENVIRONMENT

## C4.1. ASSESSMENT CONTEXT FOR ERB2B

ERB2 is developed through two main cases, both of which are based on the assumption of a constant agricultural biosphere. ERB2A involves the assumption that water resources are obtained via a well drilled into the underlying regional aquifer. By contrast, ERB2B invokes more complex considerations by assuming a ‘natural’ release of contaminated groundwater into the surface environment. The intention is to investigate the relative significance of alternative interfaces and a wide range of exposure pathways.

For ERB2B, the assumed Assessment Context is summarised below. A constant biosphere is taken to mean that the assessment should not involve assumptions for time dependent parameters. This does not mean that there are no dynamics in the system, but that the dynamical aspects occur at a constant rate (or within an unchanging cycle) and do not result changes to the system under consideration:

| | |
|---|---|
| Assessment Endpoint: | Annual individual effective dose |
| Assessment Philosophy: | ‘Equitable’ except with respect the critical group definition, which should invoke a ‘cautious’ approach |
| Repository Type: | Deep repository for long-lived solid radioactive waste. |
| Site Context: | Generic inland repository, with aquifer at accessible depth. No biosphere change. |
| Geosphere/Biosphere Interface: | ‘Natural’ discharge of contaminated groundwater to an aquifer, which subsequently discharges in the surface environment. Potential biosphere ‘receptors’ include: spring, stream/river, lake, wetland, sub-surface soils. |
| Source Term: | Constant rate of release (Bq $y^{-1}$) to the biosphere system maintained indefinitely for each radionuclide. Tc-99, I-129 and Np-237. (Same interest as for ERB2A). |
| Societal Assumptions: | Agricultural community, adopting modern practices (machinery and methods) for cultivation and animal husbandry. The resources available to the community are such that it is capable of producing locally a high proportion of the total diet of most foodstuffs. |
| Time Frame: | Up to 1 million years. |

A preliminary list of potential assessment purposes can be identified, as an indication of the sort of roles for which it is thought that the prospective model might be useful. Thus, for example, a biosphere indicator developed according to the requirements listed above could have multiple purposes, as part of the approach aimed at meeting one or more of the following:

Purpose: Guide Research Priorities (Geosphere, Near Field and Engineered System).
Proof of Concept.
Regulator/Scientific Confidence.
Guide to Site Selection.

## C4.2. BIOSPHERE SYSTEM IDENTIFICATION AND JUSTIFICATION FOR ERB2B

The principal components of the biosphere system for ERB2B have been identified as:

| | |
|---|---|
| Climate: | ZBVII Temperate (fuller explanation provided below) |
| Geology: | Sedimentary |
| Topography: | Inland, lowland, with subdued fluvial incision |
| Water Bodies: | River, lake, wetland, groundwater system (saturated and unsaturated) water distribution system, |
| Human Community: | Small farming community living off primarily local produce, (including that from terrestrial and fish farming, use of natural resources to supplement diet and other uses of natural resources). Although the climate implies a need for irrigation for agriculture, no irrigation is assumed to be necessary on the farmland receiving the discharge from the contaminated area of the aquifer. |
| Biota | Natural aquatic systems: lake, river, swamp and marsh.<br>Managed terrestrial systems: managed grasslands, improved and rough improved and rough field crop ecosystems/cultivated land tree crop ecosystems woodland and shrubland.<br>Natural terrestrial systems: temperate deciduous and evergreen forest. |
| Soil and Sediment: | Chernozem (but need to consider modification by cultivation as well as effects of permanent saturation in some areas). River and lake-bed sediments assumed to be highly organic and fine. |

## C4.3. BIOSPHERE SYSTEM DESCRIPTION FOR ERB2B

### C4.3.1. Initial consideration

The following Tables, based on the structures described in Part B, Annex BI, provide information used to develop a detailed system description.

TABLE CII. CLIMATE

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Temperature | Y | Stratification in lake. |
| Precipitation | Y | |
| Pressure | N | Low importance compared with Temperature. |
| Wind speed | Y | May need to consider creation of spray from lake. |
| Wind direction | Y | May need to consider creation of spray from lake. |
| Solar radiation | N | Low importance compared with Temperature. |
| *Temporal variability* | | |
| Diurnal | Y | As ERB2A. |
| Seasonal | Y | As ERB2A and also because water table will vary seasonally and inter-annually. |
| Interannual | Y | As ERB2A and also because water table will vary seasonally and inter-annually. |
| Decadal | Y | May need to consider flooding from abnormal rises in water table, but less relevant than flooding from lake. |
| *Spatial variability* | | |
| Latitude | N | As ERB2A. |
| Longitude | N | As ERB2A. |
| Altitude | N | As ERB2A. |
| Aspect | N | Subdued relief. |

TABLE GII. GEOLOGY

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| *Consolidated/ Solid* | | |
| Lithostratigraphy | Y | Insofar as they affect the properties of the aquifer, surface water bodies and the soil. |
| Fracture systems | Y | Insofar as they affect the properties of the aquifer, surface water bodies and the soil. |
| Weathering | Y | Insofar as they affect the properties of the aquifer, surface water bodies and the soil. |
| Erodability | N | ERB2B is not a time dependent case. |
| Mineralogy | Y | Insofar as it affects the chemistry of the aquifer. |
| *Unconsolidated / Drift* | N | Conservative to ignore, keep it simple. Was present in 2A where we wanted to put distance between the aquifer and the soil. |

It was noted that it would be helpful to have a structural description of the lithostratigraphy to support the conceptual representation of flow within, and release from, the aquifer.

TABLE TII. TOPOGRAPHY

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Altitude | Y | Low enough to permit agriculture, as in ERB2A. |
| Slope | Y | Partially defines the size of the area that we are considering and affects sediment movement. |
| Erodability | Y | Possible small influence but not strictly relevant to a “no change” biosphere. |
| Deposition rates | Y | Ditto. However, there may be some human actions that need to be considered (eg dredging lake sediment to land). |

TABLE WII. WATER BODIES

**(a) River**

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Geometry<br>*Level*<br>Basal | Y | Geometry of river channel (including possible flood plain) with respect to regional water table and seasonal flooding are relevant. |
| Flow rate | Y | Including seasonal variability. |
| Suspended sediment<br>*Composition*<br>*Load* | Y | Moves contaminated material. |
| Freeze/Thaw phenomena | Y | River freezing included only insofar as it affects seasonality of flow rate (above). |
| Hydrochemistry | Y | All aspects. For many reasons. |

### (b) Lake

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Geometry<br>*Level*<br>Basal | Y | Geometry of lake bed relevant because of connection to regional water table and effect on seasonal flooding and (temperature) stratification |
| Flow rate | Y | Including seasonal variability |
| Suspended sediment<br>*Composition*<br>*Load* | Y | Moves contaminated material. Lake may act as sink (and source if dredged). Lake sediments addressed elsewhere (Table SII) |
| Freeze/Thaw phenomena | Y | Mixing process for lake contents by disturbance of stratification. |
| Hydrochemistry | Y | All aspects. For many reasons |

### (c) Wetland

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Geometry<br>*Level*<br>Basal | Y | As ERB2A. |
| Flow rate | Y | Including seasonal variability. |
| Suspended sediment<br>*Composition*<br>*Load* | Y | Wetland may filter out suspended sediments. |
| Freeze/Thaw phenomena | Y | Freezing included only insofar as it affects seasonality of flow rate (above). |
| Hydrochemistry | Y | All aspects, especially organic. |

### (d) Saturated zone

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Geometry<br>*Level*<br>Basal | Y | Important (especially variation in level) because of connection to unsaturated zone and water courses. |
| Flow rate | Y | Including seasonal variability. |
| Suspended sediment<br>*Composition*<br>*Load* | N | Only colloids and these are treated below. |
| Freeze/Thaw phenomena | N | Recharge of aquifer not an issue. |
| Hydrochemistry | Y | Anions and cations mostly. For many reasons. |

### (e) Variably saturated zone

| Characteristic | In/Out (Y/N) | Comments |
|---|---|---|
| Geometry<br>*Level*<br>*Basal* | Y | As saturated zone. |
| Flow rate | Y | Important. |
| Suspended sediment<br>*Composition*<br>*Load* | N | Only colloids and these are treated below. |
| Freeze/Thaw phenomena | Y | Seasonal ground freezing and snowpack are relevant to infiltration but this is covered by flow rate. Hydraulic properties of soil could be affected by freeze/thaw (this is not covered under soil so included here). |
| Hydrochemistry | Y | All aspects. For many reasons. |

## TABLE HIIA. HUMAN INFLUENCE ON THE BIOSPHERE SYSTEM

| System Components | Characteristic | In/Out (Y/N) | Comments |
|---|---|---|---|
| Climate/Atmosphere | Change composition of the atmosphere | Y | Dust suspended in air. |
| | Create a local microclimate | N | No greenhouses. |
| | Controlled ventilation of buildings | Y | Affects accumulation of contamination in breathable atmosphere if source inside building. |
| Geological media | Quarrying | N | Would affect GBI but excluded because context specifies natural GBI. |
| | Mining | N | |
| Soils/sediments | Homogenisation (ploughing/tilling) | Y | |
| | Change composition (soil improvement and fertilisation) | Y | |
| | Transport, transfer (dredging and disposal of sediment) | Y | |
| | Impermeable surfaces / artificial drainage | N | No irrigation. |
| Topography | Alteration of erosion rates | N | Already assumed to be in dynamic steady state. |
| Water bodies | Change the physical shape and flows (damming) | N | Abundant surface water implies no need for modification of the natural system. |
| | Change the effective volume/level (artificial mixing, water abstraction) | N | Abundant water so that level does not change due to abstraction. |
| | Transport of water (pumped and distribution of water) | Y | For animal drinking water. |
| | Change the composition (waste water discharge) | Y | Waste discharge relevant to exposure but not to the biosphere system. |
| Natural and semi-natural ecosystems (terrestrial and aquatic) | Fire control (eg periodic burning / firebreaks) | Y | Woodland would be managed. |
| | Pest weed control | Y | |
| | Use for grazing | Y | |
| | Hunting, fishing gathering | N | Would not affect system, only give dose. |
| Managed ecosystems (terrestrial and aquatic) | Lake management | Y | Dredging necessary to maintain constant system. |
| | Planting | Y | |
| | Cropping | Y | |
| | Husbandry practices (eg seasonal relocation) | Y | |
| | Feeding and watering | Y | |

## TABLE HIIB. HUMAN ACTIVITIES LEADING TO POTENTIAL RADIATION EXPOSURE

| Biosphere System Components | Potential Exposure Mode → Exposure Routes | In/Out Y/N | Comment |
|---|---|---|---|
| Atmosphere | *Inhalation* | | |
| | Breathing | Y | All activities, indoors and outdoors, I-129 from water. |
| | *Ingestion migration route* | | |
| | Particulate deposition on foods, surfaces | Y | Eating, recreational activities, including over sediments. |
| | *External* | | |
| | Submersion | Y | All activities, indoors and outdoors from airborne concentrations. |
| Geological media | *Inhalation* | | |
| | Resuspension of dust | N | None at surface. |
| | *Ingestion* | | |
| | Incidental ingestion | N | None at surface. |
| | *External* | | |
| | Exposure to walls, ceiling and floor | N | None at surface. |

TABLE HIIB. HUMAN ACTIVITIES LEADING TO POTENTIAL RADIATION EXPOSURE (CONTINUED)

| Biosphere System Components | Potential Exposure Mode → Exposure Routes | In/Out Y/N | Comment |
|---|---|---|---|
| Soils | *Inhalation* Gaseous release into air | Y | All activities, indoors and outdoors volatilisation of I-129. |
| | *Inhalation* Soil/dust resuspension | Y | Soil disturbance activities (e.g. ploughing, walking, outdoor activities, indoor exp. from dirt tracked in) – more relevant in dry area. |
| | *Ingestion* Incidental soil ingestion | Y | Gardening, eating, recreational activities, gathering activities. |
| | *External* External irradiation (including dermal contact) | Y | Activities over/near contaminated soil, especially in discharge area. Living in contaminated buildings, built over discharge area. |
| Sediments | *Inhalation* Resuspension of dried sediments | Y | Dredging (includes tank cleaning), farming activities after land application, lake dredging. |
| | *Inhalation* Spray of suspended sediment. | N | |
| | *Ingestion* Incidental ingestion of suspended sediments | Y | Swimming. |
| | *Ingestion* Incidental ingestion of dried sediments | Y | Gardening or eating fresh vegetables from deposition areas downwind of dried sediments, recreational activities on dried sediments, lake sediments and fishing. |
| | *External* Gamma exposure from sediments | Y | Activities near water bodies (fishing and boating), Activities on exposed sediments, swimming. |
| Water bodies | *Inhalation* Spray, Aerosols, Volatile | Y | Spray (Surface waters), fishing, fish farming. |
| | *Ingestion* Drinking | Y | Drinking, incidental during swimming. |
| | *Ingestion* Incidental ingestion | Y | During bathing/swimming. |
| | *Ingestion* Eating | Y | Cooking practices. |
| | *External* Submersion in water External from water bodies | Y | Swimming, residence lake maintenance working near contaminated water bodies. |
| | Dermal Absorption Submersion in water | Y | (Should not be in ERB2A either). |
| Fauna | *Inhalation* Animal-derived particulates from incineration or cooking | Y | Incineration of waste products, cooking, occupational use of animal products. |
| | *Ingestion* Food | Y | Eating (meat, offal, milk products, eggs, gelatin), fish, wild animals and aquatic animals. Drinking milk. |
| | *External* Exposure from animals/animal products | Y | Animal husbandry, preparation of animal products, wearing clothes. |
| Plants | *Inhalation* Particulate from combustion, | Y | Fuel and waste, agricultural and other products burning, ecosystem control by fire, collection and storage. |
| | *Ingestion* Eating food | Y | Eating plant products, agricultural and other products. Drinking plant-based drinks. |
| | *External* Exposure from plants/plant products | Y | Working/Recreation, forestry, thatching, lake maintenance, storage/processing, wearing clothes, furnishings, living in buildings with material or furniture contaminated. |

TABLE BII. BIOTIC COMMUNITIES

| System Components | Characteristic | In/Out (Y/N) | Comments |
|---|---|---|---|
| Community description | Extent | Y | Minimum sufficient to encompass footprint of aquifer discharge, and adjoining affected environmental compartments, and the irrigated areas and range of behaviour of dependent communities. |
| | Heterogeneity | Y | Must allow diverse human activities and variety of exposure modes |
| | Terrestrial plants | Y | Grassland, field and tree crops, managed woodland (trees, shrubs). Representative species to be described via consideration of human diets etc. |
| *For the next categories, the screening distinguishes between species used directly by man (“resource species”) and others that may affect the biosphere (“others”)* | | | |
| | Terrestrial animals | Y | Must include animals used by man (and contributing to exposure to contaminants e.g. domesticated farm animals and native animals such as rabbits, game birds, and those that may be using the wetlands) which are “resource species” and animals whose presence affects the environment such as those modifying soils. Some species may belong to both classes. Animals lower down foodchains are not included as their effects will be included by consideration of the top of the chain. |
| | Other terrestrial organisms | Y | Fungi |
| | Aquatic plants | Y | “Resource species”<br>(– wetland: for example wild rice, water-cress, reeds, cranberries.<br>– river: no addition to wetland.<br>– lake: no addition to wetland).<br>“Others”<br>(– wetland: plants to meet dietary requirements of native animals used by man. – river: same as wetland;<br>– lake: same as wetland) |
| | Aquatic animals | Y | “Resource species”<br>(– wetland: wild fowl e.g. ducks, and game mammals.<br>– river: fish, shellfish, and others as in wetland.<br>– lake: as river but note that fish types may differ)<br>“Others”<br>– wetland: those necessary for maintaining the environment in its steady state.<br>– river: as wetland:<br>– lake: as wetland |
| | Other aquatic organisms | Y | “Resource species”<br>None<br>“Others”<br>Those necessary for maintaining the environment in its steady state. |
| | Foodchains and foodwebs | Y | See above, particularly for those described as “Resources”. Note that for some species which are wide ranging or migratory a proportion of the diet may be from outside this biosphere. Domestic animals will be relying in the main on managed plants. |

TABLE BII. BIOTIC COMMUNITIES (CONTINUED)

| System Components | Characteristic | In/Out (Y/N) | Comments |
|---|---|---|---|
| Community characteristics | Terrestrial components | Y | All the sub-items (cropping, population dynamics, canopies etc.) are relevant, and should be used to check that the descriptions of the items above are adequate for modelling. Particular items to note are:<br>Population dynamics – seasonal but long term state is steady state;<br>Plant roots – woodland trees draw water from the deeper levels of the saturated zone;<br>Behavioural characteristics – animals may roam outside the biosphere system. |
| | Aquatic components | Y | Same as terrestrial. |
| | Variation with space | Y | See Extent and Heterogeneity. |
| | Variation with time | Y | Dealt with elsewhere. |

TABLE SII. SOILS

Areal variation is accounted for by the categories below:

| System Components | Characteristic | In/Out (Y/N) | Comments |
|---|---|---|---|
| Cultivated soils | Stratification | Y | Chernozem, with mixed upper horizons which are improved |
| | Composition | Y | As Chernozem |
| | Texture | Y | As Chernozem |
| | Areal variation | Y | Will vary with farming practice |
| Managed pasture soils | Stratification | Y | As natural chernozem |
| | Composition | Y | Potentially some improvement of natural chernozem |
| | Texture | Y | More consolidated than cultivated soils |
| Woodland soils | Stratification | Y | Closer to a podzol, e.g. brown grey |
| | Composition | Y | Closer to a podzol, e.g. brown grey |
| | Texture | Y | Closer to a podzol, e.g. brown grey |
| Water margin soils | Stratification | Y | |
| | Composition | Y | Gley soils, high organic |
| | Texture | Y | Fine |
| River bed sediments | Stratification | Y | |
| | Composition | Y | Highly organic |
| | Texture | Y | Fine |
| Lake bed sediments | Stratification | Y | |
| | Composition | Y | Highly organic |
| | Texture | Y | Fine |

Further consideration of soil classification is given in Section C4.3.4, which takes account of the relationship to water table levels in the different areas.

### C4.3.2. Further development of the biosphere system description

The biosphere system description screening tables provide the basis for intial conceptual model development. In using this information to support the high-level identification of objects in the conceptual model, it is relevant to note the following:

— Topography relates to the overall description of the structure of the system and the potential significance of certain phenomena; it is therefore relevant to the modelling of transfer pathways and phenomena, but does not need to be directly translated into a physical object or environmental medium.

— The Human Community will not normally relate to a specific object in the conceptual model of the biosphere system, except in so far as it may be necessary to identify potential accumulation and migration pathways associated with the community itself. However, consideration of the human community serves as a prompt to incorporate *exposure groups* within the conceptual model for radiation exposure.

— Climate relates to certain boundary conditions imposed on the local biosphere system. These boundary conditions need to be represented within the model but climate does not directly correspond to a physical medium in its own right. In practice, however, consideration of climate serves as a prompt to consider whether *atmosphere* should be identified as a separate object, or environmental medium, within the conceptual model for radionuclide transfer. This will generally only be necessary to consider transport though the atmosphere as an explicit part of the model. Where the exposed population is assumed to live in the vicinity of the discharge from a solid waste disposal facility, this will not normally be the case.

— Water Bodies relate to two main groups of objects within the conceptual model: surface waters and subsurface waters. Each surface water body identified as belonging to the biosphere system will play a distinct role in the distribution of radionuclides (according to the 'structural' aspect of the system description) and may support a specific ecosystem or subsystem. As such, they will usually need to be identified as separate components of the conceptual model for radionuclide transport. Meanwhile, subsurface water bodies need to be coupled with the identified components of the near-surface geology (e.g. regional saturated zone and sedimentary formations that may create aquifers).

— Geology plays a role only in so far as the near-surface lithostratigraphy may help to identify distinct objects within the subsurface water system (see above).

— Biota are classified within the System Identification primarily in terms of the types of ecosystem and subsystem that are assumed to be present within the biosphere (those identified for ERB2B are listed above). The more detailed description of the biosphere system is then developed in two stages. First, each ecosystem is described in terms of its relevant plant (native/cultivated) and animal (native/domesticated) populations. The characteristics of these populations are then described as necessary. As a general rule, from the perspective of developing a conceptual model of radionuclide transfer and exposure pathways, the appropriate level of disaggregation is to identify objects at the level of native/cultivated types within terrestrial or aquatic ecosystems. A total of up to eight potential model objects (i.e. 2 [plant / animal] × 2 [native / cultivated] × 2 [terrestrial / aquatic]) may therefore be required.

— Soils are an intrinsic component of terrestrial ecosystems and it is therefore appropriate to identify physically distinct soil regions within the conceptual model tied to each terrestrial system assumed to be present within the biosphere.

### C4.3.3. Word picture development

Figure C10 places ERB2B in the context of a regional aquifer, consistent with the biosphere system description. The geosphere-biosphere interface occurs where the contaminated aquifer interacts with the soils and sediments of the river catchment illustrated in Figure C11. The nature of the different habitat areas was determined from a consideration of the slope gradient and the soil hydrology, as illustrated in Figure C12. The size of the catchment area was selected to be approximately consistent with that necessary to support the small river and lake required for ERB2B. The dimensions of the catchment are shown in Figure C13 along with the definition of the different habitat areas according to the depth to the groundwater.

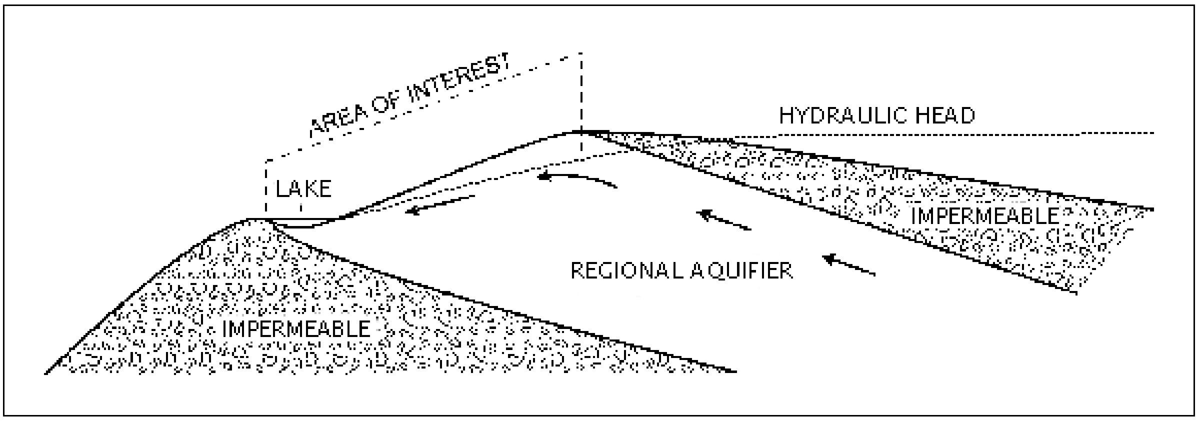



*FIG. C10. Area of Interest for ERB2B.*

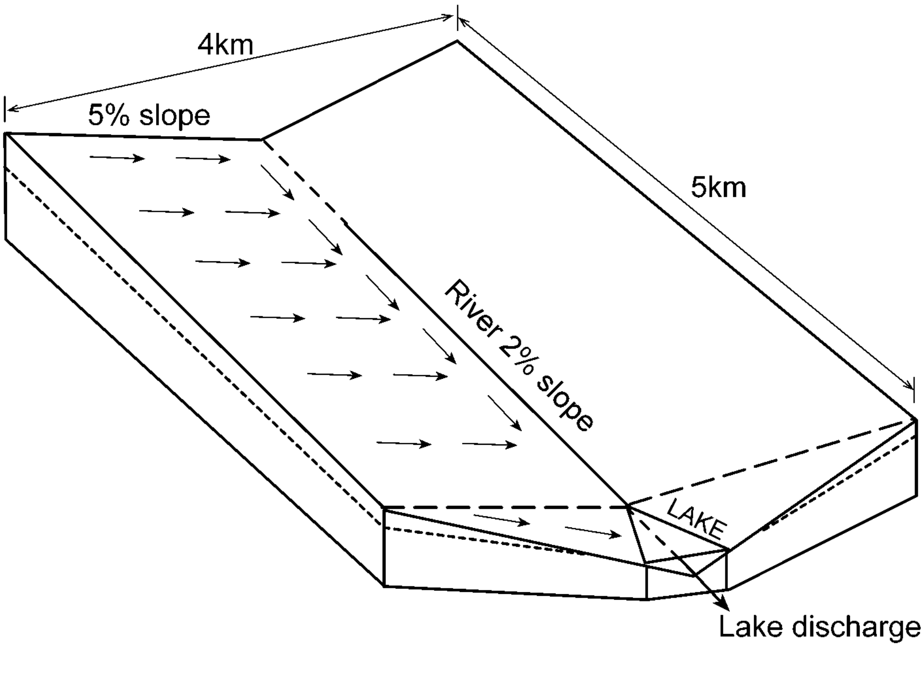



*FIG. C11. 3 Dimensional Illustration of the ERB2B Catchment.*

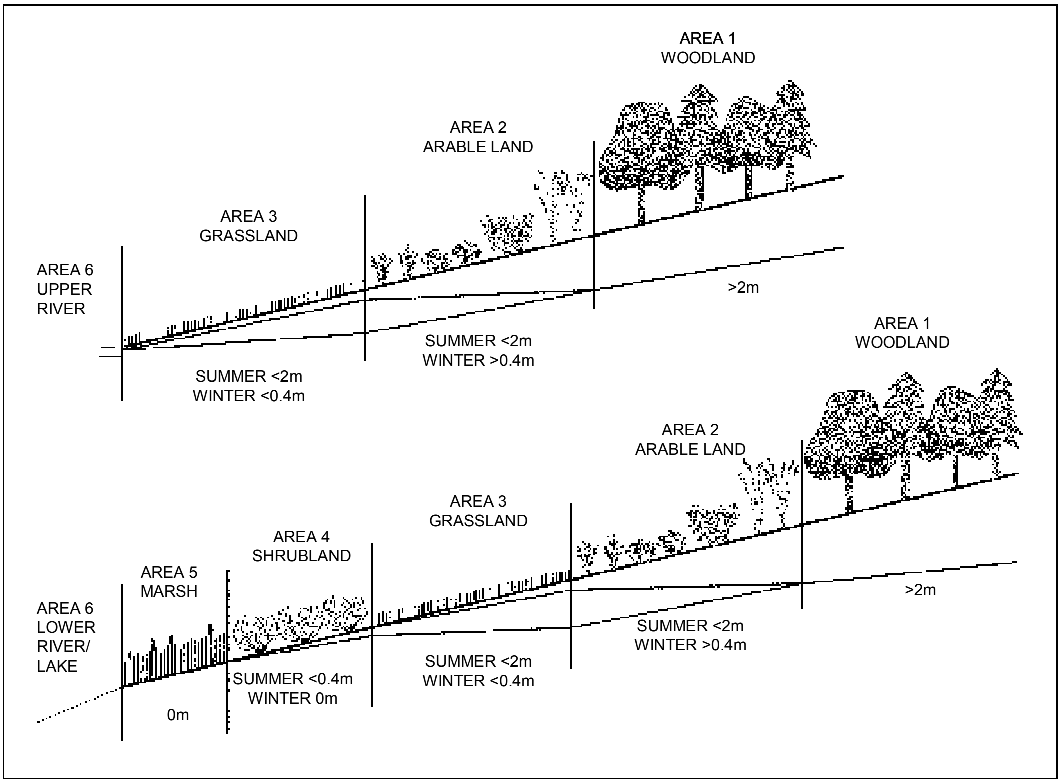



*FIG. C12. River and Lake Cross-sections Showing Depth to Aquifer.*

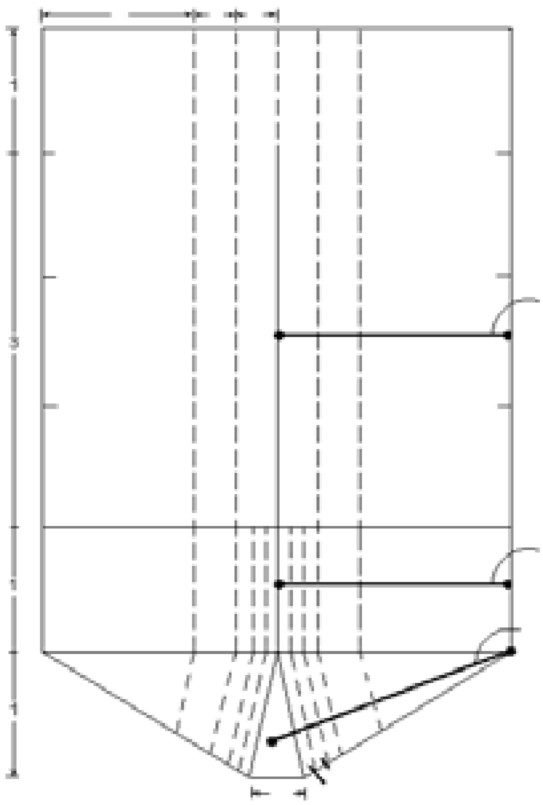


*FIG. C13. Plan View Showing the Dimensions of ERB2B.*

### C4.3.4. Consideration of water flows and other relevant data

*C4.3.4.1. Revision of soil classification*

Table C42 describes the different hydrological soil characteristics within ERB2B consistent with the HOST Classification (Boorman et al., 1995). River catchments containing the range of hydrological soil types shown in Table C42 are known to occur and can be illustrated by examples such as the Eden, Tone, Culm and Axe in the UK (Boorman et al., 1995). The horizontal areas of the habitats within ERB2B are decribed in Table C43 with the exception of the river which can only be described once a water balance has been calculated for the catchment.

TABLE C42. DESCRIPTION OF THE SOIL HYDROLOGY WITHIN ERB2B

| Habitat | Characteristic | Description |
|---|---|---|
| Area 1 – Woodland | Soil type | HOST Class 3, originally chernozem but now podzol due to woodland |
| | Soil hydrology | Groundwater normally >2 m from surface |
| Area 2 – Arable land | Soil type | HOST Class 7, well drained chernozem |
| | Soil hydrology | Groundwater normally <2 m and >0.4 m below surface |
| Area 3 – Grassland | Soil type | HOST Class 10, high organic chernozem, drainage differentiates from Area 4 |
| | Soil hydrology | Groundwater normally <2 m and <0.4 m during the winter |
| Area 4 – Shrubland | Soil type | HOST Class 10, organic rich chernozem due to slower degradation |
| | Soil hydrology | Groundwater normally <0.4 m and at surface during winter, occasionally flooded |
| Area 5 – Marshland | Soil type | HOST Class 12, organic soil, slow degradation<br>Class 10.1 of the Soil Classification for England and Wales |
| | Soil hydrology | Groundwater at surface all year round, flooded during the winter |
| Area 6 – Lake and river | Soil type | Sediment |
| | Soil hydrology | n/a |

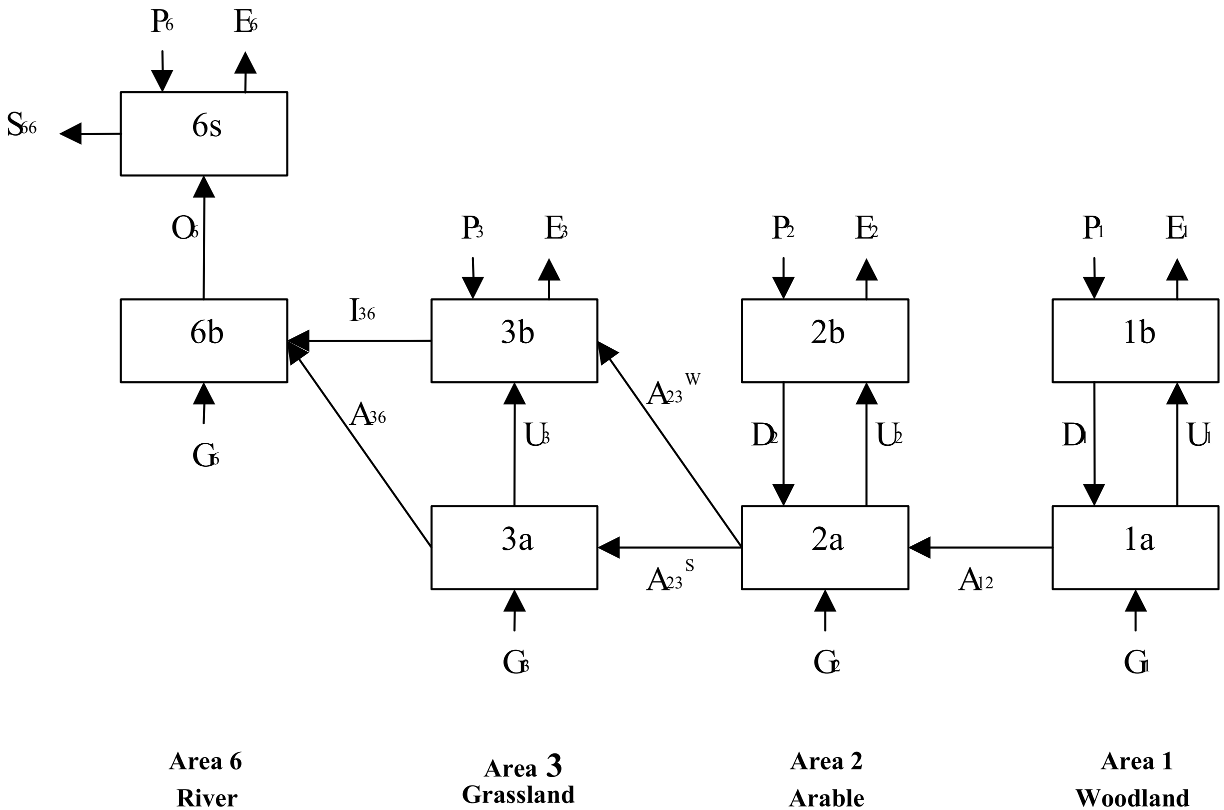
HOST Classification is taken from Boorman et al., (1995)
Soil Classification for England and Wales is taken from Avery (1980)

TABLE C43. AREA OF THE DIFFERENT HABITAT TYPES WITHIN ERB2B

| Habitat Type | Area ($km^2$) | | Total area ($km^2$) |
|---|---|---|---|
| | Adjacent to the river | Adjacent to the lake | |
| Area 1 – Woodland | 13.3 | 0.89 | 14.19 |
| Area 2 – Arable land | 3.3 | 0.50 | 3.80 |
| Area 3 – Grassland | 3.3 | 0.29 | 3.59 |
| Area 4 – Shrubland | 0 | 0.19 | 0.19 |
| Area 5 – Marshland | 0 | 0.13 | 0.13 |
| Area 6 – Lake | 0 | 0.25 | 0.25 |
| Total | 19.9 | 2.24 | 22.14 |

*C4.3.4.2. Water flows*

Figures C14 and C15 illustrate the compartmentalised water flows between the different areas of ERB2B.



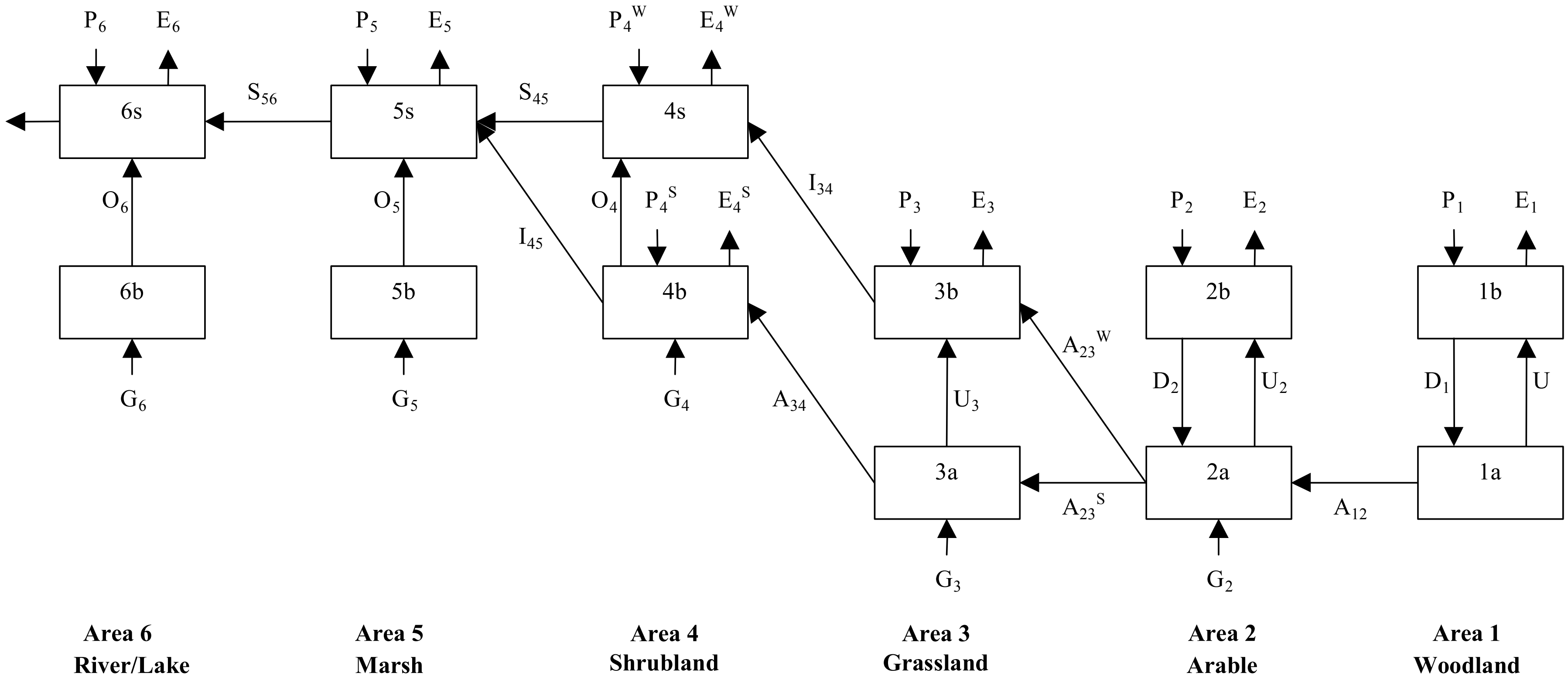

**Key:**

G = groundwater influx
P = precipitation
E = evaporation
O = water flow from sediment to river water
U = capillary rise

D = recharge
A = sub-horizontal flow from sub-soil
I = sub-horizontal flow from the surface soil
S = surface run-off

a = sub-soil
b = surface soil
s = surface water
$^S$ = during summer
$^W$ = during winter

*FIG. C14. Compartmentalised Water Flow through the Upper River Cross-section of ERB2B.*




**Key:**

G = groundwater influx
P = precipitation
E = evaporation
O = water flow from sediment to river water
U = capillary rise

D = recharge
A = sub-horizontal flow from sub-soil
I = sub-horizontal flow from the surface soil
S = surface run-off

a = sub-soil
b = surface soil
s = surface water
$^S$ = during summer
$^W$ = during winter

*FIG. C15. Compartmentalised Water Flow through the Lower River and Lake Cross-sections of ERB2B.*

**Area 1 – Woodland**

Summer (May-August):

$U_1^S = E^S - P^S$

This would create a negative sub-horizontal flow between Area 1 and Area 2 which is not possible, therefore it is assumed to be a soil moisture deficit (SMD) that is replenished in the winter.

Winter:

$D_1^S = P^W - E^W$

$A_1^W = D_1^W - U_1^S$

NB this accounts for the SMD created in the summer

Year:

$U_1 = E^S - P^S$

$D_1 = P^W - E^W$

$A_1 = D - U = P - E$

**Area 2 – Arable land**

Summer:

$U_2^S = E_2^S - P_2^S$

$A_2^S = G_2^S - U_2^S$

SMD in Area 1 means there is no summer contribution.

Winter:

$D_2^W = P_2^W - E_2^W$

$A_2^W = A_1^W + G_2^W + D_2^W$

Year:

$U_2 = E_2^S - P_2^S$

$D_2 = P_2^W - E_2^W$

$A_2^S = G_2^S - U_2^S$

$A_2^W = A_1^W + G_2^W + D_2^W$ NB goes directly to surface soil of Area 3

**Area 3 – Grassland**

Summer:

$U_3^S = E_3^S - P_3^S$

$A_3^S = A_2^S + G_3^S - U_3^S$

Winter:

$U_3^W = G_2^W$

$I_3^W = A_2^W + P_3^W - E_3^W + U_3^W$

Year:

$U_3 = E_3^S - P_3^S + G_2^W$

$A_3 = A_2^S + G_3^S - U_3^S$ NB goes directly to surface soil of Area 4 or river sediment

$I_3 = A_2^W + P_3^W - E_3^W + U_3^W$ NB goes directly to surface water of Area 4 or river sediment

**Area 4 – Shrubland**

Summer:

$I_4^S = A_3 + G_4^S + P_4^S - E_4^S$

Winter:

$O_4^W = G_4^W$

$S_4^W = I_3 + P_4^W - E_4^W + O_4^W$

Year:

$O_4 = G_4^W$
$S_4 = I_3 + P_4^W - E_4^W + G_4^W$
$I_4 = A_3 + G_4^S + P_4^S - E_4^S$

**Area 5 – Marshland**

$O_5 = G_5$
$S_5 = G_5 + I_4 + S_4 + P_5 - E_5$

**Area 6 – River**

$O_6 = G_6 + A_3 + I_3$
$S_{66} = O_6 + P_6 - E_6$

**Area 6 – Lake**

$O_6 = G_6$
$S_6 = S_{66} + S_5 + O_6 + P_6 - E_6$

*C4.3.4.3. Climate data*

The climate of ERB2B has been classified as within climate class ZBVII according to the classification scheme of Walter (1983). The climate needs to be sufficient to support the ERB2B system as described with a river and lake. There are a number of considerations to take into account when defining the climate for ERB2B:

(1) A stream or brook may be expected to have an annual flow rate of at least $10^6$ $m^3$ $y^{-1}$ before it can be considered as a permanently flowing body. The annual water flow for ERB2B should therefore amount to at least this amount at the head of the stream.

(2) Evaporation should exceed precipitation during the summer months, from May to August.

(3) The stream is not ephemeral and therefore requires a degree of water flow at the river head during the summer.

(4) There should be sub-horizontal flow from the areas receiving groundwater despite the capillary rise that occurs during the summer.

It is possible to determine the potential evaporation from temperature using the empirical formula developed by Thornthwaite (Shaw, 1984):

$$PE_m = 16 N_m \left( \frac{10 \overline{T}_m}{I} \right)^a$$

where:

$PE_m$ is potential evaporation, mm;
$N_m$ is a monthly adjustment factor related to hours of daylight;
$\overline{T}_m$ is the monthly mean temperature, ºC;
$I$ is the heat index for the year;
$a$ is related to $I$.

The heat index for the year, *I*, is given by:

$$I = \sum \left( \frac{\overline{T}_m}{5} \right)^{1.5} \qquad \text{for months } 1 \ldots 12$$

And *a* is given by:

$$a = (6.7 \times 10^{-7} I^3) - (7.7 \times 10^{-5} I^2) + (1.8 \times 10^{-2} I) + 0.49 \qquad \text{to 2 significant figures}$$

The potential evapotranspiration was converted to actual evapotranspiration depending on the habitat type and time of year as shown in Table C44. The amount of surface water, proximity of the groundwater to the soil surface and the potential degree of root penetration of the soil were considered in deriving these adjustment factors.

The climate data for ERB2B were elicited from a comparison of climate data for ZBVII (Walter, 1983) with actual climatic data from Budapest (Met'logia and Lorinc) and Odessa which are approximate ZBVII climates. The data for ERB2B were also chosen to suit the water flow criteria mentioned above. Figures C16 and C17 show a comparison between the climate data used for ERB2B and the data from Walter (1983) for Budapest and Odessa. These demonstrate consistency between climate and water balance assumptions for the ERB2B system and real systems of the same type.

The water balance calculated for ERB2B using the climate data above results in a water flow at the river head of 1.3E6 $m^3$ $y^{-1}$ and a flow of 1E4 $m^3$ over the summer months, despite the SMD of Area 1. The river discharges 6.4E6 $m^3$ $y^{-1}$ into the lake, split into 5.6E5 $m^3$ over the four summer months and 5.9E6 $m^3$ during the winter. The areas adjacent to the lake discharge 7.7E5 $m^3$ water via surface run-off from Area 5 during the year. Both these inputs, together with precipitation, evaporation and the groundwater influx of Area 6 mean that the lake discharges 7.3E+6 $m^3$ water each year, this results in a turnover rate of 9.6 $y^{-1}$.

TABLE C44. CONVERSION OF POTENTIAL TO ACTUAL EVAPORATION

| Month | Adjustment factor to potential evaporation | | | | | |
|---|---|---|---|---|---|---|
| | Area 1 Woodland | Area 2 Arable land | Area 3 Grassland | Area 4 Shrubland | Area 5 Marshland | Area 6 Lake |
| Jan | 0.9 | 0.8 | 0.8 | 0.9 | 1 | 1 |
| Feb | 0.9 | 0.8 | 0.8 | 0.9 | 1 | 1 |
| Mar | 0.9 | 0.8 | 0.8 | 0.9 | 1 | 1 |
| Apr | 0.8 | 0.8 | 0.8 | 0.9 | 1 | 1 |
| May | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 1 |
| Jun | 0.7 | 0.6 | 0.6 | 0.8 | 0.9 | 1 |
| Jul | 0.6 | 0.55 | 0.55 | 0.7 | 0.8 | 1 |
| Aug | 0.6 | 0.55 | 0.55 | 0.7 | 0.8 | 1 |
| Sep | 0.8 | 0.6 | 0.4 | 0.8 | 0.9 | 1 |
| Oct | 0.8 | 0.6 | 0.5 | 0.8 | 0.9 | 1 |
| Nov | 0.9 | 0.7 | 0.7 | 0.9 | 1 | 1 |
| Dec | 0.9 | 0.8 | 0.8 | 0.9 | 1 | 1 |
| Average | 0.8 | 0.7 | 0.675 | 0.83 | 0.93 | 1 |

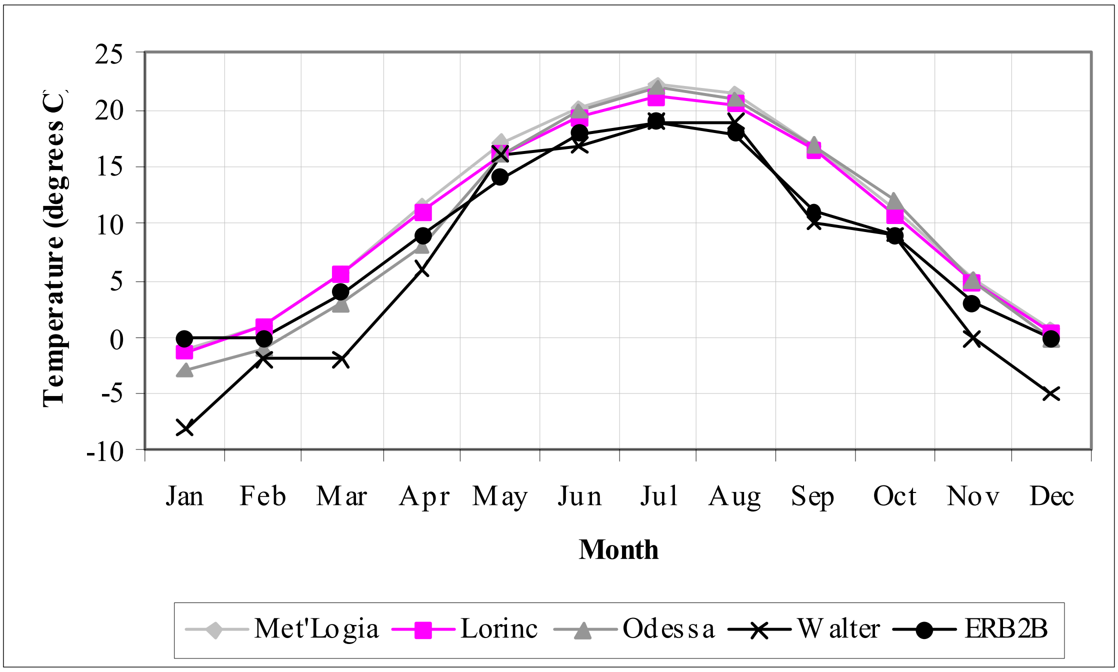



*FIG. C16. Comparison of Monthly Temperature Data used to Derive Suitable Data for ERB2B.*

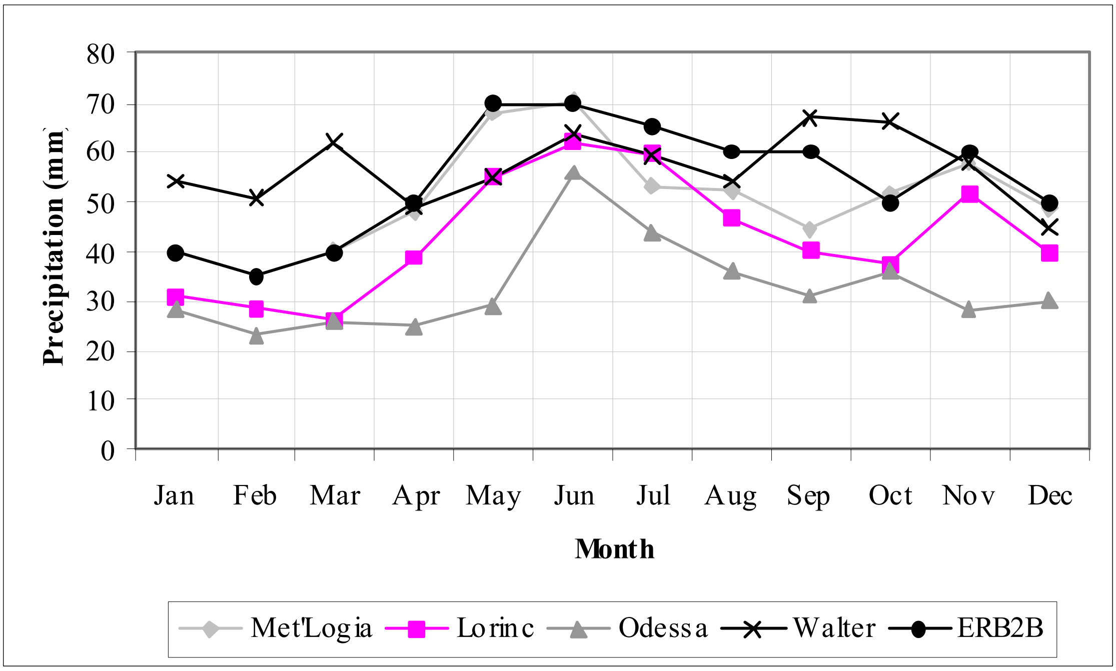



*FIG. C17. Comparison of Monthly Precipitation Data used to Derive Suitable Data for ERB2B.*

### *C4.3.4.4. River*

Once the river discharge has been calculated it is possible to define a size of circa 1E6 $m^3$ $y^{-1}$ in subdued relief for the river compartment based on some assumptions regarding the rivers flow rate. A stream may be expected to have a velocity of 1.5E6 m $y^{-1}$. The cross-sectional area of a stream can be calculated given the velocity and volume of discharge in the following manner (Shaw, 1984):

$$A = \frac{Q}{\overline{V}}$$

where:

$A$ is the cross-sectional area, $m^2$;
$Q$ is the discharge, $m^3$ $y^{-1}$;
$\overline{V}$ is the velocity, m $y^{-1}$.

The cross-sectional area of the ERB2B stream where it discharges into the lake, assuming a velocity of 1.5E6 m $y^{-1}$, is approximately 4 $m^2$. Assuming that the average cross-sectional area of the stream is half that at the point of discharge to the lake, the stream can be described with a width of 2 m and a depth of 1 m with a length of 4 km. This results in a turnover rate for the river of 8E2 $y^{-1}$.

The small area of the river compartment (8E3 $m^2$) means that the additional input of water due to the balance between precipitation and evaporation and the groundwater input (9.8E2 $m^3$ $y^{-1}$) has very little impact on the discharge rate of the river (6.4E6 $m^3$ $y^{-1}$). This means that the dimensions of the river, calculated without the additional water inputs for the river, remain sufficient to describe its dimensions.

These further developments of the system description for ERB2B allow the development of a phenomenological interaction matrix, shown in Figure C18.

## C4.4. EXPOSURE GROUP DEFINITION, FOR ERB2B

The following lifestyles have been identified from a consideration of the assessment context, the system identification and justification and the word picture for ERB2B:

| | |
|---|---|
| Arable farming: | Located in Area 2 – uses modern agricultural practices, no irrigation. |
| Livestock farming: | Located in Area 3 – uses modern animal husbandry practices, livestock housed in the winter due to low temperatures. |
| Horticultural producer: | Located in Area 2 – growing root vegetables, green vegetables and fruits using modern farming practices, no irrigation. |
| Gamekeeping: | Located in Area 4 – forages and hunts game in the woodland, shrubland, and marsh, fishes in the river and lake. |
| Fish farming: | Living in Area 5, but activity located on the lake – uses modern fish farming practices. |
| Villager: | Located in Area 2, may be allowed to have specialist occupational activities such as thatcher or tanner. |
| Infant: | 6-12 months old. |

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 1 - Wooded | Wind - aerosols and volatiles<br>Groundwater flow - sub-horizontal flow at phreatic surface<br>Surface water - surface run-off when precipitation rate exceeds vertical hydraulic conductivity (Hortonian excess)<br>Soil – solifluction<br>Use of ash as fertiliser<br>Deposition of ash from burning<br>Wood products<br>Organic detritus<br>Manuring using animal waste | Wind - aerosols and volatiles<br>Use of ash as fertiliser<br>Deposition of ash from burning<br>Wood products<br>Organic detritus<br>Animal foods | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Wood products<br>Organic detritus | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Wood products<br>Organic detritus | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Wood products<br>Organic detritus |
| 2 | Wind – aerosols and volatiles<br>Deposition of ash from burning | Area 2 - Arable Crops | Wind - aerosols and volatiles; Groundwater flow - at phreatic surface; Surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Interflow mediated by natural features and drains; Soil - solifluction<br>Deposition of ash from burning<br>Organic detritus<br>Animal foods | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus |
| 3 | Wind – aerosols and volatiles<br>Deposition of ash from burning<br>Domestic animals and animal waste | Wind - aerosols and volatiles;<br>Manuring using animal waste<br>Deposition of ash from burning | Area 3 - Grassland | Wind - aerosols and volatiles; Groundwater flow - at phreatic surface; Surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Interflow mediated by natural features and drains; Soil - solifluction<br>Deposition of ash from burning<br>Organic detritus<br>Domestic animals and animal waste | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus<br>Domestic animals and animal waste | Wind - aerosols and volatiles<br>Groundwater, interflow, surface water - stream recharge; Soil – solifluction<br>Deposition of ash from burning<br>Organic detritus |

*FIG. C18. Phenomenological Interaction Matrix of the Example 2B Biosphere System.*

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | Wind – aerosols and volatiles<br>Deposition of ash from burning<br>Wood products | Wind - aerosols and volatiles<br>Use of ash as fertiliser<br>Peat as a fertiliser<br>Deposition of ash from burning<br>Manuring using animal waste<br>Organic manuring<br>Wood products | Wind - aerosols and volatiles; Surface flow processes during seasonal flooding<br>Use of ash as fertiliser<br>Deposition of ash from burning<br>Organic manuring<br>Animal foods<br>Wood products | Area 4 - Shrubland | Wind - aerosols and volatiles; Groundwater flow - at phreatic surface; Surface run-off; Interflow mediated by natural features and drains; Soil – solifluction<br>Deposition of ash from burning<br>Organic detritus<br>Wood products | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic detritus<br>Wood products |
| 5 | Wind – aerosols and volatiles<br>Deposition of ash from burning<br>Human use of reeds | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Manuring using animal waste<br>Organic manuring<br>Human use of reeds | Wind - aerosols and volatiles<br>Deposition of ash from burning<br>Organic manuring<br>Animal foods<br>Human use of reeds | Wind - aerosols and volatiles; Surface flow processes during seasonal flooding<br>Deposition of ash from burning<br>Human use of reeds<br>Deposition of plant detritus during flooding | Area 5 - Marsh | Wind - aerosols and volatiles; Surface flow to lake water during flood recession; Groundwater flow to lake sediment;<br>Organic detritus<br>Deposition of ash from burning<br>Human use of reeds |
| 6 | Wind – aerosols, volatiles and spray<br>Water – ingestion by animals<br>Deposition of ash from burning | Wind - aerosols, volatiles and spray<br>Sediments - dredged and deposited to enhance soil; Water - ingestion by animals<br>Deposition of ash from burning | Wind - aerosols, volatiles and spray<br>Groundwater recharge from stream;<br>Sediments - dredged and deposited to enhance soil; Water - ingestion by animals, overbank flooding<br>Deposition of ash from burning | Wind - aerosols, volatiles and spray<br>Sediment - dredged and dumped;<br>Water - ingestion by animals, overbank flooding<br>Deposition of ash from burning<br>Deposition of plant detritus during flooding | Wind - aerosols, volatiles and spray<br>Surface flow during regular inundation;<br>Deposition of plant detritus during flooding<br>Sediments - deposition of riverine and locustrine sediments during flooding, or dredged and dumped; Water - ingestion by animals<br>Deposition of ash from burning | Area 6 - River and Lake |

*FIG. C18. Phenomenological Interaction Matrix of the Example 2B Biosphere System (Continued).*

### C4.4.1. Exposure pathways and exposure modes

The identification of candidate critical groups requires that exposure modes be associated with activities. This is achieved through a progressive review of the interaction of the human community with its environment, following the first four steps of the BIOMASS Methodology set out in Part B. The spatially diverse nature of the habitats identified in the ERB2B system description means that the location of exposure plays a greater role in the characterisation process than was the case for the more homogenous ERB2A biosphere. The identification of candidate critical groups relies on placing humans where they have strong interaction with those conceptual model objects which may come to have concentrations of radionuclides as a result of the release into the system.

From the system description the physical biosphere has been subdivided into six habitat areas:

1. Woodland
2. Arable Land
3. Grassland
4. Shrubland
5. Wetland
6. Water course (River/Lake)

The word picture (Section C4.3.3) only provides a limited description of the human community, noting that the local human population comprises an agricultural community, adopting modern farming practices for cultivation and animal husbandry. Resources available to the community are such that it is capable of producing locally a high proportion of the total diet for most foodstuffs. Consistent with these criteria, the biosphere system identification and justification states that it is a small farming community living off local produce where hunting/gathering of natural foodstuffs to supplement the diet may be considered.

Patterns of human behaviour should correspond to the societal context. This means that a rural community is to be considered. Activities will therefore include farming, as in the case of ERB2A, but additionally, because of the non-farming habitats, activities on (semi-natural) non-agricultural land must be considered.

Clearly, arable and pasture land activities are relevant and foodstuffs from these types of activity are available to the inhabitants of ERB2B. Occupational exposures, in the course of farming the areas of land must take their place in the description of the exposure groups. The ERB2B biosphere is in the same climate zone as ERB2A – ZB VII. As such, the agricultural practices found in ERB2A can be adopted for ERB2B. However, no irrigation is assumed to be necessary on the farmland receiving the discharge from the contaminated area of the aquifer.

Residential activities may be expected in any of the habitat regions and recreational usage of areas of land will take place in lake/river, shrubland, wetland and woodland areas. Recreation on farmland is also a possibility, as in the case of ERB2A. Such activities could include walking, picnicking, hunting, gathering, etc. Thus foodstuffs from the non-farmed areas may also form part of the ERB2B diet. Occupational activities on non-agricultural land are also likely to take place. This might include forestry, gamekeeping, coppicing, water-course management, fish-farming, etc.

TABLE C45. ERB2B BIOSPHERE SYSTEM COMPONENTS AND POTENTIAL EXPOSURE ROUTES, GIVING ILLUSTRATIVE EXAMPLES OF ACTIVITIES

| Biosphere System Components | Potential Exposure Mode, Exposure Routes | In/Out Y/N | Comment |
|---|---|---|---|
| Atmosphere | *Inhalation*<br>Breathing | Y | All activities, all habitats, indoors and outdoors,. |
| | *Ingestion migration route*<br>Particulate deposition on foods, surfaces | Y | Eating, recreational activities, including over sediments, foodstuffs from agricultural, shrubland, wetland. |
| | *External*<br>Submersion | Y | All activities, all habitats, indoors and outdoors from airborne concentrations. |
| Geological media | *Inhalation*<br>Resuspension of dust | N | No geological media at surface. |
| | *Ingestion*<br>Incidental ingestion | N | No geological media at surface. |
| | *External*<br>Exposure to walls, ceiling and floor | N | No geological media at surface . |
| Soils | *Inhalation*<br>Gaseous release into air | Y | All activities, all habitats, indoors and outdoors. |
| | *Inhalation*<br>Soil/dust resuspension | Y | Soil disturbance activities (e.g. ploughing, walking, outdoor activities, indoor exp. from dirt tracked in) – more relevant in dry areas, all habitats. |
| | *Ingestion*<br>Incidental soil ingestion | Y | Gardening, eating, recreational activities, gathering activities, all food producing habitats. |
| | *External*<br>External irradiation (including dermal contact) | Y | Activities over/near contaminated soil, especially in discharge area.<br>Living in contaminated buildings, built over discharge area, all habitats. |
| | *Inhalation*<br>Resuspension of dried sediments | Y | Farming activities after application of dredged sediments to land, lake/river dredging. |
| Sediments | *Inhalation*<br>Spray of suspended sediment. | N | Suspended sediments treated as a component of water body. |
| | *Ingestion*<br>Incidental ingestion of suspended sediments | Y | Swimming, lake/river |
| | *Ingestion*<br>Incidental ingestion of dried sediments | Y | Gardening or eating fresh vegetables from deposition areas downwind of dried sediments, recreational activities on dried sediments, lake/river sediments and fishing. |
| | *External*<br>Gamma exposure from sediments | Y | Activities near water bodies (fishing and boating), Activities on exposed sediments, swimming, lake and river habitats. |
| | *Inhalation*<br>Spray, Aerosols, Volatile | Y | Spray (Surface waters), fishing, fish farming, lake and river habitats. |
| Water Bodies | *Ingestion*<br>Incidental ingestion | Y | During bathing/swimming. |
| | Drinking | N | Drinking water supplied by an external, uncontaminated source. |
| | Eating | N | Food preparation uses piped water from an external, uncontaminated source. |
| | *External*<br>Submersion in water<br>External from water bodies | Y | Swimming, residence lake maintenance working near contaminated water bodies, lake and river habitats. |
| | *Dermal Absorption*<br>Submersion in water | N | Ruled out because of low importance relative to other pathways. |

TABLE C45. ERB2B BIOSPHERE SYSTEM COMPONENTS AND POTENTIAL EXPOSURE ROUTES, GIVING ILLUSTRATIVE EXAMPLES OF ACTIVITIES (CONTINUED)

| Biosphere System Components | Potential Exposure Mode, Exposure Routes | In/Out Y/N | Comment |
|---|---|---|---|
| Plants | *Inhalation* Particulates from harvesting, milling, combustion | Y | Fuel and waste, agricultural and other products burning, ecosystem control by fire, collection and storage, all habitats. |
| | *Ingestion* Food | Y | Eating plant products, agricultural and other products. Drinking plant-based drinks, all food producing habitats. |
| | *External* Exposure from plants/plant products | Y | Working/Recreation, forestry, thatching, lake maintenance, storage/processing, wearing clothes, furnishings, living in buildings with material or furniture contaminated, all habitats. |
| Fauna | *Inhalation* Animal-derived particulates from cooking or incineration | Y | Incineration of waste products, cooking, occupational use of animal products, all habitats. |
| | *Ingestion* Food | Y | Eating (meat, offal, milk products, eggs, gelatin), fish, wild animals and aquatic animals. Drinking milk, sources in all agricultural and game habitats. |
| | *External* Exposure from animals/ animal products | Y | Animal husbandry, preparation of animal products, wearing clothes, sources in all agricultural and game habitats. |

There is no *a priori* basis for positioning the village in the modelled system. It is assumed that the ERB2B village is located on arable land, where it would be at less risk from flooding. There is a considerably wider range of activities to be considered in the case of ERB2B compared to ERB2A. Table C45 provides a summary of the links between system components exposure routes and example activities relevant to the ERB2B human community.

— *Atmosphere:* The atmospheric components of ERB2B are found in each of the habitats. Flora, fauna and humans are in contact with it in all parts of the system, and respiration provides a route by which inhalable material can be taken up. These activities include breathing (indoors and outdoors) of radioactive vapours as well as airborne particulates. External immersion doses might also be relevant. Ingestion of deposited material also forms a potential exposure route. All potential activities, both indoors and outdoors, may give rise to exposures due to atmospheric concentrations of radionuclides.

— *Geological media:* No geologic media outcrop in the biosphere and so this category may be neglected.

— *Soils:* Soils may act as a source of volatile radionuclides. Exposures may be treated by consideration of the atmospheric concentrations. Soil particulates may also be present in air. In the context of ERB2B these can arise in a variety of ways e.g. wind action on dry soils, mechanical disturbance of soils. Individuals engaged in walking, ploughing and other outdoor activities will be exposed to airborne particulates from the mechanical disturbance of dry soils. Indoor activities can also lead to exposures since habitation and other buildings can occur in areas of the system which have become contaminated by the upwards migration of contaminants from the water table.

  Soils from the drier parts of the ERB2B system are most likely to be involved in inhalation and external exposures, especially arable and pasture land (in the summer). Saturated parts of the system (shrubland, wetland and the lake/river subsystems) are less likely to contribute to airborne dust concentrations.

  Ingestion of soil may take place as a result of deposition on foodstuffs. The unintentional ingestion of bulk material (e.g. children playing) may also be considered.

Radionuclide concentrations in soils can lead to external irradiation for persons in the locality. Activities such as agriculture (arable and pasture land), gamekeeping shrubland management (shrubland), watercourse management (wetland, river/lake), fishing, etc., must be considered. Recreational activities will also take place in the ERB2B system e.g. walking, picnicking, collecting shrubland fruits and berries, fishing, hunting. From the word-picture, the human community may be expected to construct dwellings in all parts of the system and this will lead to exposures during residential occupancy. This includes a village as well as more isolated farmhouses. The lakeside might also be considered as a residential area.

- *Sediments:* Sediments here refers to river and lake bed sediments and their treatment differs from that of soils. Individual inhabitants of the ERB2B system might come into contact with aquatic bed sediments at times of low water (where they may be treated as soils) but also predominantly during activities involved in the maintenance of the wetland and the river/lake watercourse, for example the dredging of bed sediment material to maintain flow conditions. It is unlikely that bed sediment material would be deposited on foodstuffs directly as is the case for agricultural and non-agricultural soils. Dredged material from the river/lake would be transferred to and incorporated in soil. Predominantly, exposures to bed sediments could involve external irradiation during time spent working to maintain the river/lake system.
- *Water bodies:* In contrast to ERB2A, there are a number of water bodies in ERB2B. However, the drinking water supply comes from an external non-contaminated source; livestock may be provided with water from local, contaminated sources. Irrigation of soils is assumed not to be carried out. These assumptions have been made to avoid duplicating considerations in ERB2A. Swimming and bathing in open water bodies are included and may give rise to dose via accidental ingestion or externally. Domestic usage of water for bathing and showering is neglected since included in ERB2A .
- *Plants:* In the context of the system description, the types of crop corresponding to 'modern agricultural practices' include cereals (wheat, maize, etc.), root vegetables (potatoes, carrots, etc.), as well as a range of leafy vegetables (lettuce, cabbage, etc) and fruits. In addition, there are also wild plants to be considered, such as those found in the shrubland. Berries, herbs, nuts and mushrooms may all be potentially gathered in due season. These, together with aquatic plants (e.g. watercress) would be likely to be produced in areas outside the agricultural land. While direct consumption of drinking water is not considered in ERB2B, it is possible that plant-based beverages might be important.

  Plant material can also be considered as a source of airborne contaminants if wood from contaminated areas is burnt. The shrubland might act as the source of such material through species grown for fuel or as a result of the clearance and maintenance of shrubland. The forested area might also act as a source and peat from the wetland might potentially be a method by which energy is obtained.

  External exposures can arise during occupancy of cultivated and wild areas (during work related activities as well as recreation) and bulk storage of plant material (e.g. grain silos, silage clamps) may also be considered. Clothing, furniture and buildings fashioned from local produce are also potential sources of external exposure.

  Processing of plant material may also give rise to enhanced atmospheric concentrations of contaminants (e.g. through storage of grain, silage) and the control of shrubland by managed fire may also be considered.

— *Fauna:* As with ERB2A the three exposure modes are invoked by activities involving animals and animal produce. Food is again an important consideration with it being necessary to include wild species in addition to the domesticated stock considered in ERB2A (cattle, sheep, pigs, poultry). Fish and other aquatic animals are also relevant because of the lake and river system, and there is the possibility that the local population would make use of game from the shrubland or from the forest. As with ERB2A, inhalation of animal-derived aerosols might arise during food preparation or incineration. Similarly external exposure to animals and animal products (skins, during tanning, etc.) might also be relevant, as might be the wearing of animal derived fabrics.

### C4.4.2. Identification of relevant activities

The next stage in the identification of exposure groups is to reorganise the above information by exposure mode to identify the foodstuffs and activities relevant to the assessment context. The mix of foodstuff types (semi-natural as well as agricultural) in this spatially distributed biosphere means that care must be exercised to define the source of produce as well as locations for the identified activities.

Table C46 gives examples of the ingestion mode, focussing on foodstuffs that could be consumed in the ERB2B area. Table C47 deals with the inhalation mode, listing activities at locations and Table C48 gives similar information for external irradiation. These tables provide a further opportunity to identify and screen the exposure pathways.

Table C46 lists the type of local foodstuff to be considered in the assessment. With due consideration to the system description, a larger number of potential pathways is listed. These tables provide the basis for further modelling choices.

All intentional water ingestion pathways for humans have been ruled out for ERB2B, principally to distinguish ERB2B from ERB2A. Additionally, the intake of radionuclides from contaminated water bodies via incidental ingestion is also ruled out because the associated activity – swimming in the lake/river is likely to be low duration combined with low intake.

A broad range of agricultural products is assumed to be cultivated in the ERB2B system. As for ERB2A, the classification used is fairly inclusive, with categories being:

— root vegetables;

— green vegetables; and

— cereals.

The fruit component of diet is subsumed into green vegetable consumption.

The non-agricultural regions of ERB2B are also a potential source of foodstuffs. These include nuts, berries and wild fungi. Consideration of these non-agricultural pathways raises the possibility of these same, or similar, foodstuffs being actively cultivated by the local community. As a simplifying assumption, such produce is subsumed into consumption of the wild equivalent i.e., the same foodstuff type but from a different spatial location. Previous studies (IAEA, 1995) have indicated the relevance of such pathways. It is also relevant that the shrubland area (Habitat 4) of the ERB2B system is in contact with the contaminated aquifer to a greater extent than the agricultural areas and so is liable to receive a greater proportion of the release of contaminants from the geosphere.

TABLE C46. SCREENED EXPOSURE PATHWAYS FOR ERB2B: INGESTION EXPOSURE MODE – CONSUMPTION PATHWAYS

| Consumption Medium | Consumption pathway | Location within biosphere system | Comments |
|---|---|---|---|
| Water | drinking water consumption | domestic supply external to system | To differentiate from ERB2B |
| | cooking water consumption | domestic supply external to system | To differentiate from ERB2B |
| | incidental ingestion consumption | river / lake (Habitat 6) | Assumed insignificant relative to other pathways - low duration, low intake |
| Flora | cultivated root veg. consumption | arable land (Habitat 2) | All forms of cultivated root veg., e.g., potatoes, carrots, etc. |
| | cultivated green veg. consumption | arable land (Habitat 2) | All forms of green veg. (lettuce, cabbage, etc.) |
| | cultivated cereals consumption | arable land (Habitat 2) | All forms of grain (wheat, maize, etc., rice?) |
| | *cultivated fruit consumption* | *arable land (Habitat 2)* | *Subsumed into green vegetable consumption. Anticipated problems with data collection* |
| | *cultivated fungi consumption* | *arable land (Habitat 2)* | *Subsumed into wild fungi consumption* |
| | *cultivated nuts consumption* | *arable land (Habitat 2)* | *Subsumed into wild nuts consumption* |
| | other terrestrial and aquatic cultivated flora consumption | arable land (2) and river/lake (6) | Including wild herbs |
| | wild fruit consumption | woodland/shrubland (Habitats 1 & 4) | All fruits (berries, apples, etc.) |
| | wild fungi consumption | woodland/shrubland (Habitats 1 & 4) | |
| | wild nuts consumption | woodland/shrubland (Habitats 1 & 4) | |
| | oil consumption | external supplies | The community has limited arable land area and it is assumed that this is devoted to staple crops (as above). Rape or olive oil, etc. is assumed to be imported as required, dairy oils may be used |
| | Honey | derived from local flora in all habitats | Not considered because of anticipated difficulties in data collection. May be important to diet if used as a replacement for sugar |
| | other wild flora & products | species gathered from wetland (Habitat 5) and lake river (Habitat 6) | Accounts for wetland plants (watercress, mint, etc.) from areas other than wetland - minor component of diet therefore may be subsumed into wild fruit consumption |
| Fauna | domesticated mammals (meat) | reared on pasture land (Habitat 3) | As for ERB2A, all livestock mammals are combined |
| | domesticated mammals (offal) | reared on pasture land (Habitat 3) | As for ERB2A, all livestock mammals are combined |
| | domesticated mammals (milk and dairy products) | reared on pasture land (Habitat 3) | As for ERB2A, all livestock mammals are combined |
| | *domesticated poultry (meat)* | *reared on pasture land (Habitat 3)* | *Subsumed into mammal meat consumption as ERB2A)* |
| | *domesticated poultry (offal)* | *reared on pasture land (Habitat 3)* | *Subsumed into mammal offal consumption as ERB2A)* |
| | domesticated poultry (eggs) | reared on pasture land (3) | Neglected on past experience showing this to be a minor pathway, cf. ERB2A. |

TABLE C46. SCREENED EXPOSURE PATHWAYS FOR ERB2B: INGESTION EXPOSURE MODE – CONSUMPTION PATHWAYS (CONTINUED)

| Consumption Medium | Consumption pathway | Location within biosphere system | Comments |
|---|---|---|---|
| Fauna (continued) | wild mammals (meat) | woodland (1), shrubland (4), wetland (5) | Generic animal type assumed due to anticipated problems of data collection |
| | wild mammals (offal) | woodland (1), shrubland (4), wetland (5) | Generic animal type assumed due to anticipated problems of data collection |
| | wild birds (meat) | woodland (1), shrubland (4), wetland (5) | Generic animal type assumed due to anticipated problems of data collection |
| | wild birds (offal) | woodland (1), shrubland (4), wetland (5) | Generic animal type assumed due to anticipated problems of data collection |
| | wild birds (eggs) | woodland (1), shrubland (4), wetland (5) | As for domestic poultry eggs |
| | fish | lake (Habitat 6) | |
| | *crustaceans & molluscs* | *lake (Habitat 6)* | *Subsumed into fish, minor contribution to diet, and anticipated problems of data collection* |
| | other native wild fauna | woodland (1), shrubland (4), wetland (5), river/ lake (6) | As an unspecified pathway it may be ruled out as a minor contribution to diet |
| Soil/ Sediment | unintentional bulk material | all habitats (1, 2, 3, 4, 5, 6) | Unintentional direct soil ingestion |
| | | all foodstuffs | Unintentional soil/sediment intake with foodstuffs |
| | material suspended in water | drinking/domestic water | Suspended sediments, ignored because non-contaminated water supply is provided |
| | deliberate ingestion | all habitats (1, 2, 3, 4, 5, 6) | Ruled out as soil pica is regarded as an illness |

**Notes:**

Shaded pathways are those screened out of ERB2B, italics denote subsumed pathways.

Other foodstuffs are ruled out of the assessment model altogether. Vegetable oil is more likely to be produced where there is a greater proportion of available arable land. Given the conditions in ERB2B, it is considered more likely that staple crops (listed above) would be preferred. Vegetable oils are therefore not considered.

Locally produced honey may be a potential foodstuff. It is ruled out, however, on the grounds that it is unlikely to be a major component of diet unless used in place of sugar. Assuming modern agricultural practices and a modern society, this is unlikely; it is also assumed that sugar is imported. Other produce is subsumed into the wild fruit component of diet. These assumptions are consistent with the statement about a *high proportion* of dietary requirement being met from local sources, without the need to assume that all foodstuffs are obtained from local production.

The non-agricultural flora pathways are:

— wild fruits;

— wild nuts;

— wild fungi; and

— other wild flora.

Locally reared livestock in the agricultural regions is likely to be the same as in ERB2A and, as before, agriculturally derived meat consumption is subsumed into a single pathway. This can be best achieved, from a data perspective, by combining transfer factors to give an aggregated value suitable for the range of pathways to be considered. Domesticated poultry consumption is also subsumed into this category. Similar subsuming takes place for offal consumption, including poultry. Following the ERB2A example, eggs are neglected as, on past relevant experience, they contribute little to overall radiological exposure.

In the representation of wild animal types, data availability concerns lead to the combination of all foodstuff types into a single generic animal type, providing meat and offal. Wild bird eggs are neglected.

The aquatic biosphere in ERB2B allows for fish consumption but other aquatic species are subsumed into this pathway as they are likely to provide a small contribution to diet in ERB2B.

The list of animal and animal product consumption pathways relevant to ERB2B is:

- meat from domesticated animals;
- offal from domesticated animals;
- milk and dairy products from domesticated animals;
- meat from wild animals (game meat); and
- fish.

Table C46 also allows for other unspecified native wild fauna. The above range of pathways provides scope for subsuming into one of the main types should survey data indicate that a specific foodstuff type has been missed.

Consumption of soils and sediments is only treated insofar as there is contamination of foodstuffs. As with ERB2A, soil pica is ruled out as it is considered extreme behaviour (Simon, 1998).

The inhalation mode results from radionuclide concentrations in the atmosphere as airborne particulates, gases and volatile materials. The activities that the local population is engaged in during exposure may be classified as occupational, recreational, domestic and sleeping. A range of relevant activities in these categories, organised according to location, is given in Table C47.

TABLE C47. TABLE OF SCREENED EXPOSURE PATHWAYS FOR ERB2B: INHALATION EXPOSURE MODE (AIRBORNE DUST, PARTICULATES AND VOLATILES)

| Pathway | Location within biosphere system | Example activities |
|---|---|---|
| Occupational | contaminated agricultural land (2, 3) | Plant burning outdoors*<br>General farm work<br>Ploughing/digging*<br>Animal husbandry<br>Harvesting*<br>Milking (indoors)<br>Plant processing and storage (in- and outdoors)<br>Manuring (in- and outdoors) |
| | contaminated non-agricultural land (4, 5) | General maintenance activities<br>Forestry<br>Gamekeeping<br>Hunting ruled out from Assessment Context |
| | on/by lake/river (5, 6) | General maintenance activities<br>Watercourse maintenance (e.g., dredging)<br>Fish farming<br>Reed cutting |
| | non-contaminated land (1) | As for contaminated non-agricultural land |
| Recreational | contaminated agricultural land (2, 3) | Walking<br>Picnicking (including fires)<br>Gardening<br>Playing (children)<br>Camping<br>Bird watching |
| | contaminated non-agricultural land (4, 5) | Walking<br>Picnicking (including fires)<br>Gardening<br>Playing (children)<br>Camping<br>Bird watching<br>Hunting/gathering |
| | on/by lake/river (6) | Walking<br>Picnicking (including fires)<br>Playing (children)<br>Camping/houseboat<br>Bird watching<br>Hunting/gathering/fishing<br>Boating<br>Swimming |
| | non-contaminated land (1) | As for contaminated land |
| Domestic | all habitats (1, 2, 3, 4, 5, 6) | General domestic activities, ambient dust conc.<br>General domestic activities, high dust conc.* |
| Sleeping | all habitats (1, 2, 3, 4, 5, 6) | At home<br>Camping/houseboat |

**Notes:**

Shaded pathways are those screened out of ERB2B, italics denote subsumed pathways.

‘*’ denotes relatively high airborne concentration pathways. () denotes habitat number.

Occupational activities on agricultural land remain as envisaged in ERB2A and this is reflected in the example activities in Table C47. New to ERB2B are the occupational activities on the non-agricultural land. Activities which take place in the forest, shrubland and on the wetland must also be accounted for. These would include forestry, hunting and gamekeeping and general maintenance work

There are also specialised activities associated with the lake/river system. Maintenance of the water course may require dredging and reed cutting and, as well as other general work. There is also the possibility of fish farming in the lake.

Recreational activities in ERB2B can take place over a wider range of habitats than is the case for ERB2A. Although recreation on the farmed land cannot be ruled out, the other areas provide more opportunity for a broader range of activities with fewer restrictions on access. Many of the example activities may take place in all habitats but hunting and gathering is much more relevant to the non-agricultural areas. On the lake there is the possibility of houseboats and fishing may be included as well. Swimming in the lake and river is also possible.

As noted above, the village is assumed to be located on the arable land but there is no reason to preclude dwellings in any of the habitats. A farmhouse on the pasture land is likely and forestry workers or gamekeepers might be anticipated to reside outside the village and close to their areas of work. Similarly, fishermen could potentially reside in houseboats on the lake. Each of the areas might have an associated garden for growing vegetables although nearer the valley bottom this would be less likely to be feasible owing to the proximity of the phreatic surface to the soil. Domestic buildings are also used for sleeping, with associated lower breathing rates.

Table C48 provides the subdivision for the external irradiation pathways. Again the categorisation is into occupational, recreational, domestic and sleeping. All activities identified in Table C47 are relevant. The issue for external irradiation is whether the individual is shielded from the contaminated medium or not.

Table C49 summarises the exposure pathways to be considered in ERB2B, together with the model habitat areas involved.

### C4.4.3. Identification and qualitative description of candidate critical groups for ERB2B

As with ERB2A there are different agricultural groups to be considered – arable farmers and livestock farmers. Each of these groups is associated with specific locations within the ERB2B biosphere and has associated consumption preferences. The broad assumptions made are comparable with those adopted for ERB2A, so that results can be compared and the significance of the different interfaces and system compnents identified.

Arable farmers consume high quantities of arable produce, livestock farmers consume high quantities of meat and meat products. On this basis a Gamekeeper group, working in the Shrubland and Wetland habitats, might be expected to consume larger amounts of game and wild produce.

TABLE C48. TABLE OF SCREENED EXPOSURE PATHWAYS FOR ERB2B: EXTERNAL EXPOSURE MODE

| Pathway | Location within biosphere system | Example activities |
|---|---|---|
| Occupational | on contaminated agricultural land (2, 3) | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | on contaminated non-agricultural land (4, 5) | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | on/by lake river | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | non-contaminated land (1) | As for contaminated land |
| Recreational | on contaminated agricultural land (2, 3) | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | on contaminated non-agricultural land (4, 5) | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | on/by lake river | Activities as for inhalation but distinguish shielded and unshielded exposure<br>Clothing |
| | non-contaminated land (1) | As for contaminated land |
| Domestic | all habitats (1, 2, 3, 4, 5, 6) | General domestic activities<br>Clothing |
| Sleeping | all habitats (1, 2, 3, 4, 5, 6) | Bedding<br>Clothing |

TABLE C49. SUMMARY OF EXPOSURE PATHWAYS CONSIDERED IN ERB2B

| Ingestion | | |
|---|---|---|
| Consumption pathways | Habitat area | Aggregated and subsumed pathways |
| Domesticated animals: | | |
| – Meat | 3 | all livestock meat including poultry |
| – Offal | 3 | all livestock offal including poultry |
| – Milk and dairy products | 3 | all cattle |
| Wild animals: | | |
| –Meat | 1,4,5 | generic game animal |
| –Birds | 1,4,5 | generic game bird |
| – Fish | 6 | including shellfish and crustaceans |
| Agricultural produce: | | |
| – Root vegetables | 2 | all root veg. |
| – Cereals | 2 | all cereals |
| green vegetables | 2 | all remaining veg., including fruit |
| Non-agricultural produce: | | |
| – Wild fruits | 1, 4 | generic wild fruit |
| – Wild nuts | 1, 4 | generic nuts - all nuts |
| – Wild fungi | 1, 4 | all fungi |
| – Other wild flora | 1, 5 | herbs etc. |
| – Soil | 1, 2, 3, 4, 5 | soil contamination of foodstuffs |

TABLE C49. SUMMARY OF EXPOSURE PATHWAYS CONSIDERED IN ERB2B (CONTINUED)

| Inhalation and External | | |
|---|---|---|
| Pathway | Habitat area | Comments |
| Occupational: | | |
| – Farmwork (high dust loading) | 2, 3 | ploughing, harvesting, plant burning |
| – Farmwork (normal dust loading) | 2, 3 | general work, milking, plant processing, animal husbandry |
| – Gamekeeping and forestry | 1, 4, 5 | |
| – Watercourse maintenance | 6 | |
| – Fish farming | 6 | |
| – Reed cutting | 5, 6 | |
| – Clothing | 1, 2, 3, 4, 5, 6 | |
| Recreational: | | |
| – Walking, picnicking | 1, 2, 3, 4, 5 | |
| – Gardening | 1, 2, 3, 4, 5 | |
| – Camping/houseboat | 1, 2, 3, 4, 5, 6 | |
| – Bird watching | 1, 2, 3, 4, 5 | |
| – Hunting/gathering/fishing | 1, 4, 5, 6 | |
| – Boating | 6 | |
| – Swimming | 6 | |
| – Clothing | 1, 2, 3, 4, 5, 6 | |
| Domestic: | | |
| – General activities, normal dust conc. | 1, 2, 3, 4, 5 | |
| – General activities, high dust conc. | 1, 2, 3, 4, 5 | |
| – Houseboat | 6 | |
| – Clothing | 1, 2, 3, 4, 5, 6 | |
| Sleeping: | | |
| – Bedding and clothing | 1, 2, 3, 4, 5, 6 | |

Fish farmers are identified as another potential group, since this specific occupation is not unreasonable and would be likely to lead to high interaction with the lake and river. High occupancy of the lake/river would be expected with activities being undertaken to maintain the quality of the lake. Residency by the lake might be imagined with high consumption of fish and potentially other game pathways.

Recreational use of land would be most likely to focus on the shrubland, wetland and lake/river although it may be assumed that some groups (e.g. the farming groups) might make use of agricultural land for leisure activities.

A Villager group, residing in Habitat 2 is worthy of consideration as a control group. This group would be defined by median values of consumption of all foodstuffs combined with recreational activities. In contrast to the corresponding group in ERB2A, this group would also receive external and inhalation doses during domestic residence (including sleeping) since the mechanism of release to the biosphere would lead to the area of the village becoming contaminated.

For consistency with the ERB2A analysis, an infant group residing in the village is defined.

From the above discussion seven exposure groups are identifiable as appropriate to a radiological assessment of the ERB2B region. Five of these – Arable Farmer, Livestock Farmer, Horticultural Producer and Villager and Infant – have counterparts in ERB2A but two others – Gamekeeper and Fish Farmer are additional. The characteristics of the groups are as follows:

**EG1, Arable Farmer** – Based in Habitat 2 (arable land), the farm produces root crops and cereals for local consumption and export. These two pathways provide the key consumption characteristics of this group, with **cereals** and **root crops** consumed at the critical levels. All other foodstuffs are consumed at central levels but are produced locally. Water for domestic and agricultural purposes is provided by a piped supply system derived from uncontaminated sources. Inadvertent soil intake is also assumed to be at high levels as a result of activities in high dust environments.

Farmhouse and buildings are located in Habitat 2 so that occupational, domestic and sleeping time are spent in this area of the system. Leisure activities for this group are assumed to be split between the shrubland, wetland and lake/river. The forest is not visited by this group (since it is a non-contaminated region). Recreational activity is not assumed to take place on agricultural land because the lower parts of the valley are likely to become more contaminated because of proximity to the aquifer.

**EG2, Livestock Farmer** – Based in Habitat 3 (pasture land) the farm rears livestock for local consumption and export. **Meat products** and **milk and dairy products** are the characterising pathways for this group set to critical consumption rates, all other pathways are set to central values. Water for domestic purposes is obtained from the uncontaminated supply which is also used for most agricultural purposes, including livestock watering, particularly during stabling during the cold winter months. During the summer the animals may obtain some or all of their water from the river. Inadvertent soil intake for the Livestock Farmer group is also assumed to be at high levels as a result of activities in high dust environments.

Farmhouses and buildings are located in Habitat 3 so that occupational, domestic and sleeping time is spent in the same area of the system. Leisure activities for this group are assumed to be the same as for the Arable Farmer group as there is no *a priori* reason to do otherwise.

**EG3, Horticultural Producer** – Based in Habitat 2 (arable land) the produce is **green** and **root vegetables** for local consumption and export and these pathways are set to critical levels for this group. All other pathways are set to central levels. Water supplies for domestic and agricultural purposes are from the uncontaminated external source.

Houses and buildings are located in Habitat 2 so that occupational, domestic and sleeping time are spent in the same area of the system. Leisure activities for this group are assumed to be the same as for the Arable Farmer group.

**EG4, Gamekeeper** – Based in Habitats 4 (shrubland) and 5 (Wetland) the chief characteristic of this group is the high occupancy of these regions. Critical consumption of **game** and **wild foods** is assumed with other foodstuffs being consumed at central levels, however a case could be made for replacing agriculturally produced meat with game. Water supplies for this group are assumed to come from the uncontaminated off-site piped water supply.

In this group four consumption pathways are set to high consumption but none of these is a major component of diet. High consumption of these pathways is not likely to imply an excessively and unrealistically high calorific intake.

It is assumed that members of this group reside in dwellings located on the shrubland so that domestic activities and sleeping take place there. Leisure activity is assumed to be spent on shrubland, wetland and lake/river, as for the other groups. Occupational activities are carried out in both shrubland and wetland. This group takes care of maintenance of the shrubland and wetland, including such activities as reed cutting.

**EG5, Fish Farmer** – Being commercially active on or near the lake, the Fish Farmer group is assumed to reside on a houseboat on the lake. Water supplies are obtained from the piped water system. As a producer of fish, consumption of this pathway is set to the critical consumption rate. This is assumed to be the only high consumption pathway, all other foodstuffs are consumed at central levels. Other pathways could be involved but a choice has been made to keep the characterisation simple.

Leisure activity takes place on the three areas identified for the other groups but occupational residency is confined to the lake river system (including shore and bank sides). With a commercial interest in maintaining the quality of lake water, this group carries out dredging of the river/lake system.

**EG6, Villager** – The village is located in the arable land habitat (2) where all domestic, sleeping and occupational activities take place. The Villagers Group consume all foodstuffs at central levels. Leisure activity is as defined for the other groups, activities taking place on shrubland, wetland and lake/river.

Gardening is a leisure activity pursued by this group and it is assumed that root crops and green vegetables are produced in the garden. However, there is no significance to the assessment since this is the same soil area as arable crops.

**EG7, Infant** – In the age range 6 – 12 months, this group represents infants in the village. All foodstuffs are set to central levels for this age range and it is assumed that all domestic, sleeping and recreational activities take place in and around the village in Habitat 2. There are no occupational activities associated with this group.

Some common features of diet are relevant. All water supplies are obtained from uncontaminated sources. Water and milk consumption for farmers are expected to be high because of the strenuous nature of the work involved. For groups other than Gamekeeper and Fish Farmer, game and fish consumption are obtained during recreational activities or by trading via the village. All vegetable oils and sugars are imported.

Table C50 summarises relevant characteristics of the seven ERB2B exposure groups.

TABLE C50. SUMMARY OF CANDIDATE CRITICAL GROUPS CHARACTERISTICS CONSIDERED IN ERB2B

| | source | pathway | level of consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | EG1 | EG2 | EG3 | EG4 | EG5 | EG6 | EG7 |
| | | | Arable Farmer | Livestock Farmer | Hort. Producer | Gamekeeper | Fish Farmer | Villager | Infant |
| consumption pathways | 3 | meat | central | *critical* | central | central | central | central | central |
| | 3 | offal | central | *critical* | central | central | central | central | central |
| | 3 | milk and dairy produce | central | *critical* | central | central | central | central | central |
| | 4, 5 | game | central | central | central | *critical* | *critical* | central | central |
| | 4, 5 | game offal | central | central | central | *critical* | central | central | central |
| | 6 | fish | central | central | central | central | central | central | central |
| | 2 | root vegetables | *critical* | central | *critical* | central | central | central | central |
| | 2 | green vegetables | central | central | *critical* | central | central | central | central |
| | 2 | cereals | *critical* | central | central | central | central | central | central |
| | 4, 5 | wild fruits | central | central | central | *critical* | central | central | central |
| | 4, 5 | wild nuts | central | central | central | *critical* | central | central | central |
| | 4, 5 | wild fungi | central | central | central | *critical* | central | central | central |
| | 2, 3, 4, 5,6 | soils directly and indirectly | *critical* | *critical* | central | central | central | central | central |
| | external | water | *critical* | *critical* | *critical* | central | central | central | central |
| | external | oils | central | central | central | central | central | central | central |
| | external | sugar | central | central | central | central | central | central | central |

| | class | activity | location where activity takes place | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | EG1 | EG2 | EG3 | EG4 | EG5 | EG6 | EG7 |
| | | | Arable Farmer | Livestock Farmer | Hort. Producer | Gamekeeper | Fish Farmer | Villager | Infant |
| inhalation and external | occupational | farmwork (high dust loading) | 2 | 3 | 2 | - | - | - | - |
| | | farmwork (normal dust loading) | 2 | 3 | 2 | - | - | - | - |
| | | gamekeeping and forestry | - | - | - | 4, 5 | - | - | - |
| | | watercourse maintenance | - | - | - | - | 5, 6 | - | - |
| | | fish farming | - | - | - | - | 6 | - | - |
| | | village activities | - | - | - | - | - | 2 | - |
| | | clothing | 2 | 3 | 2 | 4, 5 | 5, 6 | 2 | - |
| | recreational | walking, picnicking | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 2 |
| | | Gardening | - | - | - | - | - | 2 | - |
| | | camping | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 2 |
| | | houseboat | - | - | - | - | - | - | - |
| | | bird watching | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 2 |
| | | hunting/gathering | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 4, 5 | 2 |
| | | fishing | 6 | 6 | 6 | 6 | 6 | 6 | 2 |
| | | boating | 6 | 6 | 6 | 6 | 6 | 6 | 2 |
| | | swimming | 6 | 6 | 6 | 6 | 6 | 6 | 2 |
| | | clothing | 4, 5, 6 | 4, 5, 6 | 4, 5, 6 | 4, 5, 6 | 4, 5, 6 | 4, 5, 6 | 2 |
| | domestic | general, normal dust conc. | 2 | 3 | 2 | 4 | 6 | 2 | 2 |
| | | general, high dust conc. | 2 | 3 | 2 | 4 | 6 | 2 | 2 |
| | | houseboat | - | - | - | - | 6 | - | - |
| | | clothing | 2 | 3 | 2 | 4 | 6 | 2 | 2 |
| | sleeping | sleep | 2 | 3 | 2 | 4 | 6 | 2 | 2 |
| | | clothing | 2 | 3 | 2 | 4 | 6 | 2 | 2 |
| | | bedding | 2 | 3 | 2 | 4 | 6 | 2 | 2 |

Although identified earlier, shaded entries play no role as their function has been subsumed into other groups or have been excluded.

## C4.5. MODEL DEVELOPMENT FOR ERB2B

### C4.5.1. Identification of conceptual model objects

The ERB2B system can be divided into 6 separate areas depending on the nature of the interaction with the groundwater. The transfer of radionuclides can occur within and between each of these areas. The features of the different areas vary, through variations in the depth and characteristics of the soil/sediment layers for example. For this reason, Conceptual Model Objects (CMOs) have been described for each area. The substantially more complex system description necessary to address the ERB2B assessment context required more iterations between system description and model development than was required for ERB2A. The term CMO is introduced here to distinguish between the habitats associated with each area and the conceptual objects common to each of them.

**Area 1 – Woodland**

| | |
|---|---|
| Aquifer | normally >2 m below soil surface |
| Atmosphere | |
| Soil | podzol derived from an original chernozem |
| Plants | emperate deciduous and evergreen trees and plants typical of such a managed woodland ecosystem, fungi |
| Animals | rodents, small mammals, birds |
| Human community | manage woodland |

**Area 2 – Arable land**

| | |
|---|---|
| Aquifer | normally 0.4 - 2 m below soil surface |
| Atmosphere | |
| Soil | well drained chernozem |
| Plants | arable crops |
| Animals | rodents, small mammals, birds |
| Human community | arable farming |

**Area 3 – Grassland**

| | |
|---|---|
| Aquifer | normally <2 m below soil surface and <0.4 m during the winter |
| Atmosphere | |
| Soil | high organic chernozem with drainage |
| Plants | meadow pasture |
| Animals | domestic animals, rodents, small mammals, birds |
| Human community | livestock farming |

**Area 4 – Shrubland**

| | |
|---|---|
| Aquifer | normally <0.4 m below soil surface and at the surface during the winter |
| Atmosphere | |
| Soil | organic rich chernozem |
| Plants | biomass crops, shrubland species |
| Animals | rodents, small mammals, birds |
| Human community | biomass crops, cutting peat |

**Area 5 – Wetland**

| | |
|---|---|
| Aquifer | at surface all year round |
| Atmosphere | |
| Soil | organic rich soil, slow degradation |
| Plants | marsh species |
| Animals | rodents, small mammals, birds, |
| Human community | collect dietary food substitutes |

**Area 6 – Lake and river**

| | |
|---|---|
| Aquifer | intrudes into sediment |
| Atmosphere | |
| Sediment | highly organic |
| Surface water bodies | lake and river |
| Plants | aquatic plants |
| Animals | fish, birds |
| Human community | fish farming |

### C4.5.2. Conceptual representation of radionuclide transport pathways

Due to the large number of CMOs for ERB2B, the radionuclide transfer matrix has been sub-divided to improve its managability. The first matrix (Figure C19) describes transfers between the different areas within ERB2B and the remaining matrices (Figures C20–C26) describe the transfers within each sub-area.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | Area 1 - Wooded | X | X | X | X | X | X | X |
| 2 | X | Area 2 - Arable Crops | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to soil - surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Soil to soil- Interflow mediated by natural features and drains<br>Soil to soil – solifluction<br>Plant to animal - transfer to animals as fodder | X | X | X | X | Atmosphere to sink – aerosols, gas, dust and detritus |
| 3 | X | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Animal to soil - manuring | Area 3 – Grassland | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to soil - surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Soil to soil - Interflow mediated by natural features and drains<br>Soil to soil – solifluction | X | X | X | Atmosphere to sink – aerosols, gas, dust and detritus |
| 4 | X | Plant to soil - disposal of ash to augment nutrient status | Aerosols to atmosphere – aerosols, gas, dust and detritus | Area 4 – Shrubland | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to soil - surface run-off when precipitation rate exceeds vertical hydraulic conductivity; Soil to soil - Interflow mediated by natural features and drains<br>Soil to soil – solifluction<br>Soil to soil - surface flow processes during occasional flooding | X | X | Atmosphere to sink – aerosols, gas, dust and detritus |

*FIG. C19. Radionuclide Transfer Interaction Matrix for Transfers between the Different Habitat Areas within the ERB2B Catchment.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 5 | Animals to soil – migrating birds depositing excreta | Animals to soil – migrating birds depositing excreta | Animals to soil – migrating birds depositing excreta | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to soil - surface flow processes during occasional flooding<br>Animals to soil – migrating birds depositing excreta | Area 5 – Wetland | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to water - surface flow processes during flooding<br>Soil to water – runoff when not flooded<br>Plants - organic detritus by surface waters | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Soil to water - surface flow processes during flooding<br>Soil to water – runoff when not flooded<br>Plants - organic detritus by surface waters | Atmosphere to sink – aerosols, gas, dust and detritus |
| 6 | X | Sediments to soil - dredged and deposited to enhance soil | Sediments to soil - dredged and deposited to enhance soil | Water to soil - surface flow processes during occasional flooding<br>Sediment to soil – following dredging or flooding<br>Water to animals – ingestion by animals | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Water to soil - surface flow processes during flooding<br>Sediment to soil – following dredging or flooding<br>Water to animals – ingestion by animals | Area 6 - River | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Water to water – discharge containing suspended sediment<br>Sediment to sediment – bed flow | Atmosphere to sink – aerosols, gas, dust and detritus |
| 7 | X | Sediments to soil - dredged and deposited to enhance soil | Sediments to soil - dredged and deposited to enhance soil | Water to soil - surface flow processes during occasional flooding<br>Sediment to soil – following dredging or flooding<br>Water to animals – ingestion by animals | Atmosphere to atmosphere – aerosols, gas, dust and detritus<br>Water to soil - surface flow processes during flooding<br>Sediment to soil – following dredging or flooding<br>Water to animals – ingestion by animals | Atmosphere to atmosphere – aerosols, gas, dust and detritus | Area 6 - Lake | Atmosphere to sink – aerosols, gas, dust and detritus<br>Water to sink – discharge from lake |
| 8 | X | X | X | X | X | X | X | Sink |

*FIG. C19. Radionuclide Transfer Interaction Matrix for Transfers between the Different Habitat Areas within the ERB2B Catchment (continued).*

**NOTES to Figure C19:**

'X' = not relevant.

The human community is located as mentioned in WD9 although not considered as a significant transfer medium.

Export of food is not considered and important transfer process although that exported could go to the human community in any of the habitat areas.

Although it is recognised that in a real system a small area of connectivity may exist between the shrubland and the river, the conceptualised distribution of the different habitat areas rules it out in this example.

*Leading diagonal elements*

Area 1 (1,1) has no significant radionuclide transfer interaction with the other habitat areas due to the lack of contamination.

Areas 1 and 2 are assumed not to flood.

Area 5 (5,5) has standing water but not a connected waterbody.

*Off diagonal elements*

(2,1) Landslip out – constant biosphere; felling not to Area 2; animals and humans not a significant transport vector; timber transport trivial.

(1,2) Negligible groundwater flow up-slope; solifluxion is a downslope process; surface water flow is a downslope process.

(2,4) transfer of building material is not considered a significant transfer although it may be considered as an exposure.

(3,4) Flooding is not considered a significant transfer due to low frequency and limited up-slope movement of material.

(5,4) Dominated by surface flow during seasonal flooding; limited head gradient for groundwater flow.

(4,5) Transfer of material may occur between the wetland and shrubland during flooding although we have trouble in being able to describe the method of mathematical representation due to a lack of understanding of both water flows during flooding and the distribution of rainfall within the catchment.

Disposal of lake bed sediments could be to either Areas 2 and 3 or to Areas 4 and 5 depending on whether it would/could enhance soil properties or whether dumped (either because not required or poor quality, e.g. contaminated by chemically toxic materials such as heavy metals).

Animals on Area 3 could drink water from either the river (3,6) or the lake (3,7).

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 1 Aquifer | X | X | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Area 1 Atmosphere | X | X | X | X |
| 3 | X | X | Area 1 Soils | X | X | X |
| 4 | X | X | X | Area 1 Plants | X | X |
| 5 | X | X | X | X | Area 1 Animals | X |
| 6 | X | X | X | X | X | Area 1 Sinks |

*FIG. C20. Radionuclide Transfer Interaction Matrix for Transfers within the Woodland of the ERB2B Catchment.*

**NOTES to Figure C20:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the surface soils such that the assumption of uniform contamination is no longer valid, it is considered as part of the soil.

*Off diagonal elements*

(3,1) No mass transfer because no weathering of parent material, transfer of radionuclides to the deep soil may occur with fluctuations in the phreatic surface although these are not considered to be significant.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,1) Uptake by deep rooted trees may be significant although we are not addressing it here due to similar uptake in the shrubland area, this may not cover all of the processes that may be significant in a woodland system so this may be addressed in a side calculation.

The lack of significant transfers from the contaminated aquifer within the woodland means that there is no significant contamination within the woodland system and therefore no significant transfers of radionuclides.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 2 Aquifer | X | Through variations in the water table, capillary action, gas phase transport and burrowing animals | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Area 2 Atmosphere | Gas, aerosol, dust and detritus deposition | Gas, aerosol, dust and detritus deposition and active uptake | X | Wind blown gas, aerosol, dust and detritus |
| 3 | Recharge maintaining the constant concentration in the aquifer | Suspension, volatilisation and gas | Area 2 Soils | Root uptake and soil splash | X | Soil, detritus and water during run-off |
| 4 | X | Transpiration, respiration, volatilisation, gases and ash from burning, detritus | Weathering, leaf litter, root exudates, ploughed in detritus and ash from burning | Area 2 Plants | X | X |
| 5 | X | X | X | X | Area 2 Animals | X |
| 6 | X | X | X | X | X | Area 2 Sinks |

*FIG. C21. Radionuclide Transfer Interaction Matrix for Transfers within the Arable Area of the ERB2B Catchment.*

**NOTES to Figure C21:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Storage of farm products has been ignored as it has been shown not to be of significance in ERB2A.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the surface soils such that the assumption of uniform contamination is no longer valid, it is considered as part of the soil.

Soil (2,2) includes soil dwelling animals, transfers associated with these animals are therefore considered to occur within the soil.

Animals (5,5) are not considered not to be a significant transfer medium in the arable area.

*Off diagonal elements*

(3,1) No mass transfer because no weathering of parent material.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is considered trivial, except for tritium.

(1,3) No mass transfer because no penetration of aquifer by soil solids; recharge is only of relevance because it is a component of maintaining a unit concentration in aquifer.

(2,4) Transfers to atmosphere as pollen and seeds are considered trivial.

(6,4) Cropping was shown to be an insignificant transfer process in ERB2A and is therefore ignored.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 3 Aquifer | X | Through variations in the water table, capillary action, gas phase transport and burrowing animals | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Area 3 Atmosphere | Gas, aerosol, dust and detritus deposition | Gas, aerosol, dust and detritus deposition and active uptake | Gas, aerosol, dust and detritus inhalation | Wind blown gas, aerosol, dust and detritus |
| 3 | Recharge maintaining constant concentration in the aquifer | Suspension, volatilisation and gas | Area 3 Soils | Root uptake and soil splash | Ingestion | Soil, detritus and water during run-off |
| 4 | X | Transpiration respiration, volatilisation, detritus | Weathering, leaf litter, root exudates, detritus | Area 3 Plants | Ingestion | X |
| 5 | X | Respiration, and GI tract gases | Excreta | Excreta | Area 3 Animals | Export food, waste and manure |
| 6 | X | X | X | X | X | Area 3 Sinks |

*FIG. C22. Radionuclide Transfer Interaction Matrix for Transfers within the Grassland Area of the ERB2B Catchment.*

**NOTES to Figure C22:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Storage of farm products has been ignored as it has been shown not to be of significance in ERB2A.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the surface such that the assumption of uniform contamination is no longer valid, it is considered as part of the soil.

Soil (2,2) includes soil dwelling animals, transfers associated with these animals are therefore considered to occur within the soil.

*Off diagonal elements*

(3,1) No mass transfer because no weathering of parent material.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is considered trivial, except for tritium.

(1,3) No mass transfer because no penetration of aquifer by soil solids; recharge is only of relevance because it is a component of maintaining a unit concentration in aquifer.

(2,4) Transfers to atmosphere as pollen and seeds are considered trivial.

(2,5) Combustion of animal carcasses is considered to be an insignificant transfer process.

(3,5) Excreta includes both solid and liquid material; disposal of carcasses is considered insignificant due to likely export of material or consumption.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 4 Aquifer | X | Through variations in the water table, capillary action, gas phase transport and burrowing animals | Some root uptake by deeper rooted species | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Area 4 Atmosphere | Gas, aerosol, dust and detritus deposition | Gas, aerosol, dust and detritus deposition and active uptake | Gas, aerosol, dust and detritus inhalation | Wind blown gas, aerosol, dust, detritus |
| 3 | Recharge maintaining constant concentration in the aquifer | Suspension, volatilisation, gas | Area 4 Soils | Root uptake and soil splash | Ingestion | Soil, detritus, water during flooding and run-off |
| 4 | Root exudates from deep rooted species maintaining constant concentration in the aquifer | Transpiration respiration, volatilisation, detritus, gas and ash from burning | Weathering, leaf litter, root exudates, detritus | Area 4 Plants | Ingestion | Export of biomass crop, food |
| 5 | X | Respiration | Excreta, death and decay | Excreta | Area 4 Animals | Export as food |
| 6 | X | X | X | X | X | Area 4 Sinks |

*FIG. C23. Radionuclide Transfer Interaction Matrix for Transfers within the Shrubland Area of the ERB2B Catchment.*

**NOTES to Figure C23:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the surface soils and sediments such that the assumption of uniform contamination is no longer valid, it is considered as part of the soil/sediment.

Soil (2,2) includes soil dwelling animals, transfers associated with these animals are therefore considered to occur within the soil.

*Off diagonal elements*

(2,1) There is no direct transfer from the aquifer to the atmosphere despite the soil being saturated during the winter due to the definition of the aquifer above.

(3,1) No mass transfer because no weathering of parent material.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is probably trivial, except for tritium.

(1,3) No mass transfer because no penetration of aquifer by soil solids; recharge is only of relevance because it is a component of maintaining a unit concentration in aquifer.

(5,3) The animals are able to consume both water and soil from the soil as it is saturated during the winter.

(2,4) Transfers to atmosphere as pollen and seeds are considered trivial.

(6,4) Biomass crops are exported and burnt.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | Area 5 Aquifer | X | Discharge through the soil | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Area 5 Atmosphere | Gas, aerosol, dust and detritus deposition | Gas, aerosol, dust and detritus deposition and active uptake | Gas, aerosol, dust and detritus inhalation | Wind blown gas, aerosol, dust and detritus |
| 3 | Recharge maintaining the constant concentration in the aquifer | Suspension - including organic particulates; volatilisation and gas | Area 5 Soils | Root uptake, soil splash and adhesion of soil | Ingestion | Soil, detritus, water during flooding and run-off |
| 4 | X | Transpiration and respiration, deritus volatilisation | Weathering, leaf litter, root exudates, detritus | Area 5 Plants | Ingestion | Export of wild foods, reeds |
| 5 | X | Respiration | Excreta, death and decay | Excreta | Area 5 Animals | Export of game, migration of birds |
| 6 | X | X | X | X | X | Area 5 Sinks |

*FIG. C24. Radionuclide Transfer Matrix for Transfers within the Wetland Area of the ERB2B Catchment.*

**NOTES to Figure C24:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the surface soils and sediments such that the assumption of uniform contamination is no longer valid, it is considered as part of the soil/sediment.

Soils (3,3) includes associated standing water and animals contained within both the soil and standing water.

Reeds may be an important plant in the wetland habitat (4,4) due to the possibility of exposure via reed cutting and use.

*Off diagonal elements*

(3,1) No mass transfer because no weathering of parent material.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is probably trivial, except for tritium.

(1,3) No mass transfer because no penetration of aquifer by soil solids; recharge is only of relevance because it is a component of maintaining a unit concentration in aquifer.

(2,3) Volatilisation may be important in a wetland habitat for some radionuclides.

(4,3) Uptake by plants from wetland soils will be different to other habitat areas, high nutrient status and low soil oxygen means that only specialised plants can grow.

(2,4) Volatilisation of I-129 may be significant in a wetland habitat; transfers to atmosphere as pollen and seeds are considered trivial; no burning of reeds considered as it is covered with the burning of biomass crops from the shrubland habitat.

(6,5) Birds may migrate and deposit excreta to the shrubland or any other habitat area.

(3,6) Peat extraction may be covered with a side calculation due to the conflict with the maintenance of a constant biosphere, transfer to arable soils is therefore not considered.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | River Aquifer | X | Discharge through sediment | X | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | River Atmosphere | X | Gas, aerosol, dust and detritus, spray, dust, detritus deposition | Gas, aerosol, dust and detritus, spray, dust, detritus deposition and active uptake | Gas, aerosol, dust and detritus, spray, dust, detritus inhalation (ducks, otters etc) | Wind blown gas, aerosol, spray, dust, detritus |
| 3 | Recharge maintaining constant concentration in the aquifer | Suspension and volatilisation | Riverbed Sediments | Resuspension, diffusion, advection, gas evolution | Uptake of water, nutrients and gases adhesion | Ingestion (fish, ducks etc) | X |
| 4 | X | Evaporation, evolution of volatiles, spray, evolution of aerosols | Deposition of suspended sediment, diffusion | River Surface Water Bodies | Uptake of water, nutrients and gases adhesion of suspended sediment | Ingestion and surface absorption | Outflow |
| 5 | X | Transpiration and respiration | Detritus from death and decay, root exudates | Detritus from living plants and death and decay | River Plants | Ingestion (fish, ducks etc) | X |
| 6 | X | Respiration | Excreta, death and decay | Excreta, death and decay | X | River Animals | Export as food |
| 7 | X | X | X | X | X | X | River Sinks |

*FIG. C25. Radionuclide Transfer Matrix for Transfers within the ERB2B River.*

**NOTES to Figure C25:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the river bed sediments such that the assumption of uniform contamination is no longer valid, it is considered as part of the river bed sediment.

Riverbed sediment (3,3) includes both sediments, some parent material and associated water.

Plants (5,5) include both submerged and emerged plants.

*Off diagonal elements*

(3,1) Negligible pressure induced pumping; no mass transfer because no weathering of parent material.

(4,1) River assumed to be underlain by bed sediments so no direct water-aquifer connection.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is probably trivial, except for tritium.

(2,3) Riverbed sediments may be exposed to the atmosphere during dry periods.

(4,3) Bioturbation is less important than physical resuspension.

(6,3) Uptake could include that by invertebrates.

(2,4) Includes bubble bursting for aerosols; do not forget surface microlayer enrichment phenomena; transfers as pollen and seeds are considered trivial.

(6,4) Uptake is generally modelled by a concentration ratio for aquatic animals – this accounts for ingestion, via gills and through body surface; for aves and mammalia ingestion is thought to be the primary route.

| | 1 | 2 | 3 | 4 | 5 | 6 | 8 |
|---|---|---|---|---|---|---|---|
| 1 | Lake Aquifer | X | Discharge through sediment | X | X | X | To adjacent aquifers maintaining constant concentration |
| 2 | X | Lake Atmosphere | X | Gas, aerosol, dust and detritus, spray, dust, detritus deposition | Gas, aerosol, dust and detritus, spray, dust, detritus deposition and active uptake | Gas, aerosol, dust and detritus, spray, dust, detritus inhalation (ducks, otters etc) | Wind blown gas, aerosol, spray, dust, detritus |
| 3 | Recharge maintaining constant concentration in the aquifer | Suspension and volatilisation | Lakebed Sediments | Resuspension, diffusion, advection, gas evolution | Uptake of water, nutrients and gases adhesion | Ingestion (fish, ducks etc) | X |
| 4 | X | Evaporation, evolution of volatiles, spray, evolution of aerosols | Deposition of suspended sediment, diffusion | Lake Surface Water Bodies | Uptake of water, nutrients and gases adhesion of suspended sediment | Ingestion and surface absorption | Outflow |
| 5 | X | Transpiration and respiration | Detritus from death and decay, root exudates | Detritus from living plants and death and decay | Lake Plants | Ingestion (fish, ducks etc) | X |
| 6 | X | Respiration | Excreta, death and decay | Excreta, death and decay | X | Lake Animals | Export as food |
| 8 | X | X | X | X | X | X | Lake Sinks |

*FIG. C26. Radionuclide Transfer Matrix for Transfers within the ERB2B Lake.*

**NOTES to Figure C26:**

'X' = not relevant.

Radioactive decay is assumed to occur throughout, except where the source term is assumed to maintain a constant concentration.

Several different exposure groups may utilise the contaminated system.

*Leading diagonal elements*

Aquifer (1,1) is defined as part of the homogenous and uniformly contaminated regional aquifer. Where the saturated zone has interacted with the lake bed sediments such that the assumption of uniform contamination is no longer valid, it is considered as part of the lake bed sediment.

Lakebed sediment (3,3) includes both sediments, some parent material and associated water.

Plants (5,5) include both submerged and emerged plants.

Nothing is gained by the inclusion of a fish farm in the lake area of ERB2B that cannot be considered with wild fish, the inclusion of fish-farming does impose constraints on the lake size, it is therefore to be ignored in ERB2B.

*Off diagonal elements*

(3,1) Negligible pressure induced pumping; no mass transfer because no weathering of parent material.

(4,1) Lake assumed to be underlain by bed sediments so no direct water-aquifer connection.

(6,1) Eliminated by definition of flux/concentration boundary conditions within upper part of aquifer; use of no flow boundary conditions at lake (vertical) and at base of underlying aquifer in which a uniform concentration occurs.

(4,2) Active uptake, e.g. sulphur dioxide and carbon dioxide in photosynthesis etc.

(5,2) Skin absorption is probably trivial, except for tritium.

(2,3) Lakebed sediments may be exposed to the atmosphere during dry periods.

(6,3) Uptake could include that by invertebrates.

(2,4) Includes bubble bursting for aerosols; do not forget surface microlayer enrichment phenomena; transfers as pollen and seeds are considered trivial.

(6,4) Uptake is generally modelled by a concentration ratio for aquatic animals – this accounts for ingestion, via gills and through body surface; for aves and mammalia ingestion is thought to be the primary route.

### C4.5.3. Audit of the biosphere system description and conceptual model for ERB2B

In order to demonstrate comprehensive coverage of potentially relevant FEPs, the biosphere system description and conceptual model have been audited against a generic FEP list as shown in Table C51.

TABLE C51. CHECKLIST FOR APPEARANCE OF FEPS FROM THE GENERIC FEP LIST OF BIOSPHERE EVENTS AND PROCESSES IN THE BIOSPHERE SYSTEM DESCRIPTION AND CONCEPTUAL MODEL

| FEP | In/ Out | Note |
|---|---|---|
| Root Uptake (3.1.3.1.1) | In | Soil to plant transfer |
| Respiration (3.1.3.1.2) | In | Plant to atmosphere transfer |
| Transpiration (3.1.3.1.3) | In | Plant to atmosphere transfer |
| Intake by fauna (3.1.3.1.4) | In | Plant to animal transfer |
| Interception (3.1.3.1.5) | In | Atmosphere to plant transfer via deposition |
| Weathering (3.1.3.1.6) | In | Plant to soil transfer |
| Bioturbation (3.1.3.1.7) | In | Implicit in selection of compartment sizes |
| Translocation (3.1.3.2.1) | In | Within plant |
| Animal metabolism (3.1.3.2.2) | In | Soil, plant and atmospheric transfers to animals |
| Evaporation (3.1.4.1.1) | In | Soil and water body transfers to atmosphere |
| Gas transport (3.1.4.1.2) | In | Atmospheric transfers between adjacent Areas and to sinks |
| Aerosol formation and transport (3.1.4.1.3) | In | Surface water body to atmosphere transfer |
| Washout and wet deposition (3.1.4.1.5) | In | Implicit in deposition from atmosphere |
| Dry deposition (3.1.4.1.5) | In | Implicit in deposition from atmosphere |
| Infiltration (3.1.4.2.1) | In | Transfer within soil |
| Percolation (3.1.4.2.2) | In | Transfer within soil |
| Capillary rise (3.1.4.2.3) | In | Transfer within soil |
| Groundwater transport (3.1.4.2.4) | In | Transfer between Areas |
| Multiphase flow (3.1.4.2.5) | Out | Not needed, gas release separable from water flow regime in soil |
| Surface run-off (3.1.4.2.6) | In | Transfer between Areas |
| Discharge (3.1.4.2.7) | In | Transfers between Areas and to water bodies |
| Recharge (3.1.4.2.8) | In | Transfer within soil |
| Transport in surface water bodies (3.1.2.4.9) | In | Transfer within surface water bodies and from surface water bodies to sink |
| Erosion (3.1.4.2.10) | Out | Due to maintenance of constant environment |
| Landslides and rock falls (3.1.4.3.1) | Out | Due to maintenance of constant environment |
| Sedimentation (3.1.4.3.2) | In | Surface water body to sediment transfer |
| Sediment suspension (3.1.4.3.3) | In | Sediment to surface water body transfer |
| Rain splash (3.1.4.3.4) | In | Soil to plant transfer as soil splash |
| Dissolution/precipitation (3.1.4.4.1) | In | Subsumed into adsorption/desorption as a control on migration |
| Adsorption/desorption (3.1.4.4.2) | In | Transfer within soil |
| Colloid formation (3.1.4.4.3) | In | Considered in defining degree of adsorption/ desorption |
| Artificial soil fertilisation (3.2.1.1) | Out | No imported fertiliser |
| Chemical pollution (3.2.1.2) | Out | Due to maintenance of constant environment |
| Acid rain (3.2.1.3) | Out | Due to maintenance of constant environment |
| Construction (3.2.2.1) | Out | Maintenance of a constant biosphere |
| Water extraction by pumping (3.2.2.2) | Out | Negligible influence |
| Water recharge by pumping (3.2.2.3) | Out | No recharge of the groundwater by pumping |
| Dam building (3.2.2.4) | Out | Natural lake |
| Land reclamation (3.2.2.5) | Out | Due to maintenance of constant environment |
| Ploughing (3.2.3.1) | In | Transfer from plants to soil and implicit in suspension from soil to air |
| Well supply (3.2.3.2) | Out | Covered in ERB2A |
| Other water supply (3.2.3.3) | Out | Covered in ERB2A |
| Irrigation (3.2.3.4) | Out | Covered in ERB2A |
| Recycling of bulk solid materials (3.2.3.5) | In | Transfer from plants and animals to soils and between Areas due to manuring and amending soil with ash |
| Artificial mixing of water bodies (3.2.3.6) | Out | Negligible compared to river discharge |
| Dredging (3.2.3.7) | In | Transfer between Areas and transfer from sediment to humans in Area 6 |
| Controlled ventilation (3.2.3.8) | Out | |
| Water treatment (3.2.4.1) | Out | No need to treat the water as human drinking water is taken from outside the system |
| Air filtration (3.2.4.2) | Out | |
| Food processing (3.2.4.3) | In | |

### C4.5.4. Mathematical Model for ERB2B

*C4.5.4.1. Intercompartmental transfer processes*

The mathematical representation of the intercompartmental transfer processes takes the form of a matrix of transfer coefficients that allow the compartmental inventories to be calculated using a set of first order linear differential equations. The general equation is set out in Section C3.5.3.

*C4.5.4.2. Radionuclide transfer process representation*

The transfers are described for each of the 6 different habitat types associated with ERB2B, arable land, grassland, shrubland, wetland, river and lake. It was agreed not to model radionuclide migration to, in and from the woodland part of the system on the basis of low radiological significance. However, the woodland part of the system does affect the choice of parameter values used in the radionuclide migration and accumulation model. All the processes retained in the interaction matricies after review in Section C4.6 are included in the mathematical model.

Radionuclide migration between the different habitat areas of ERB2B will differ between the habitat areas adjacent to the river and those areas adjacent to the lake due to the different relative sizes of the habitats. For this reason, the two sections are separated in the model resulting in two of each habitat type, that adjacent to the river and that adjacent to the lake. Human-mediated transfers to these habitat areas, such as the transfer of manure, ash and sediment are apportioned in the ratio of the destination habitat areas.

Table C52 lists the plant types modelled in the different habitat areas and the assumptions made in selecting which data were used to represent them in the model.

TABLE C52. LIST OF PLANT TYPES MODELLED IN THE DIFFERENT HABITAT AREAS AND THE ASSUMPTIONS CONCERNING THE DATA USED IN THEIR REPRESENTATION

| Habitat Area | Description | Plant Type | Modelled as |
|---|---|---|---|
| Area 2 | Arable land | Green vegetables<br>Root vegetables<br>Grain | Green vegetables<br>Root vegetables<br>Grain |
| Area 3 | Grassland | Pasture | Pasture |
| Area 4 | Shrubland | Wild fruit<br>Wild nuts<br>Wild fungi<br>Biomass crops | Wild fruit<br>Wild nuts<br>Wild fungi<br>Other native wild flora |
| Area 5 | Wetland | Wetland species | Other native wild flora |

*Arable Land (Area 2)*

**Groundwater source term to sub-soil compartment**

The radionuclide source term to the sub-soil of Area 2 due to the influx of groundwater, $W_2$, Bq $y^{-1}$, is given by:

$$W_2 = G_2 C_g$$

where:

$G_2$ is the volume of groundwater source term to the subsoil of Area 2, $m^3$ $y^{-1}$;
$C_g$ is the radionuclide concentration in the groundwater, 1 Bq $m^{-3}$.

*Capillary Rise of Soil Water from the Sub-Soil to the Surface Soil*

The transfer of radionuclides from the sub-soil compartment to the surface soil compartment of Area 2 due to capillary rise (and other upward processes), λU2, y-1, is given by:

$$\lambda_{U2} = \frac{U_2}{R_{2a}\theta_{2a}V_{2a}}$$

where:

$U_2$ is the volume of capillary rise from the sub-soil to the surface soil compartment, $m^3$ $y^{-1}$;
$R_{2a}$ is the retardation coefficient for the sub-soil compartment of Area 2;
$\theta_{2a}$ is the water filled porosity of the sub-soil compartment of Area 2;
$V_{2a}$ is the volume of the sub-soil compartment of Area 2, $m^3$.

The $R_{2a}$ term is calculated using the following equation:

$$R = 1 + \frac{(1-\theta_{t2a})\rho_{2a}}{\theta_{2a}} K_{d2a}$$

where:

$\theta_{t2a}$ is the total porosity of the sub-soil compartment of Area 2;
$\rho_{2a}$ is the grain density of the sub-soil compartment of Area 2, kg $m^{-3}$;
$K_{d2a}$ is the sorption coefficient of the soil in the sub-soil compartment of Area 2, $m^3$ $kg^{-1}$.

The $V_{2a}$ term is calculated using the following equation:

$$V_{2a} = Area_2 \ d_{2a}$$

where:

$Area_2$ is the area of the surface soil compartment of the Area 2 habitat, $m^2$;
$d_{2a}$ is the thickness of the surface soil compartment of the Area 2 habitat, m.

**Recharge of soil water to the sub-soil from the surface soil**

The transfer of radionuclides to the sub-soil compartment from the surface soil compartment due to infiltration (and other downward processes), $\lambda_{D2}$, $y^{-1}$, is given by:

$$\lambda_{D2} = \frac{D_2}{R_{2b}\theta_{2b}V_{2b}}$$

where:

$D_2$ is the volume of recharge from the surface soil compartment of Area 2, $m^3$ $y^{-1}$;
$R_{2b}$ is the retardation coefficient for the surface soil compartment of Area 2;
$\theta_{2b}$ is the water filled porosity of the surface soil compartment of Area 2;
$V_{2b}$ is the volume of the surface soil compartment of Area 2, $m^3$.

**Transfer of detritus to the local watercourse**

A proportion of the plants grown on the arable areas of ERB2B will be lost to the local watercourse and ultimately the lake due to the movement of detritus. The plants modelled in the arable area are root vegetables, green vegetables and grain.

The radionuclides transferred to the lake due to the movement of contaminated detritus and surface soil are all assumed to become part of the local watercourse. The root vegetables, green vegetables and grain are assumed to be grown in rotation in the arable area, therefore the annual transfer rate is the average of that for the three crops. The transfer rate of radionuclides from Area 2 to the local watercourse due to the loss of this detritus, $\lambda_{P26}$, $y^{-1}$, is given by:

$$\lambda_{P26} = \frac{P_{26}\Sigma_{plants}\left((CF_{plant} + Soil_{plant})Y_{plant}Area_2\right)}{3(1-\theta_{t2b})\rho_{2b}V_{2b}}$$

where:

$P_{26}$ is the fraction of primary productivity in Area 2 lost as detritus to the local watercourse;
$CF_{plant}$ is the concentration factor from root uptake for the plant, Bq $kg^{-1}$ (fresh weight crop)/Bq $kg^{-1}$ (dry weight soil);
$Soil_{plan}$ is the soil contamination on the crop, kg (dry weight soil) $kg^{-1}$ (fresh weight crop);
$Y_{plant}$ is the above ground fresh weight yield of the plant, kg $m^{-2}$ $y^{-1}$;
$Area_2$ is the area of habitat Area 2, $m^2$;
$\theta_{t2b}$ is the total porosity of the surface soil compartment of Area 2;
$\rho_{2b}$ is the grain density of the surface soil compartment of Area 2, kg $m^{-3}$,

It is assumed that the root vegetable, green vegetable and grain crops are grown in rotation on the arable land, therefore the long-term removal rate of radionuclides from the soil due to plant uptake is the arithmetic average for the three crop types.

**Transfer of surface soil to the local watercourse due to erosion**

Some of the surface soil of the arable area will be lost due to erosion, a proportion of this material will end up the local. The transfer rate of radionuclides from the surface soil of Area 2 to the local watercourse due to erosion, $\lambda_{E26}$, $y^{-1}$, is given by:

$$\lambda_{E26} = \frac{E_{26}}{V_{2b}}$$

where:

$E_{26}$ is the transfer of surface soil from Area 2 to the local watercourse, $m^3$ $y^{-1}$.

**Sub-horizontal flow to the sub-soil of Area 3**

The rate of transfer of radionuclides from the sub-soil compartment of Area 2 to the subsoil of Area 3, $\lambda_{A23}$, $y^{-1}$, is given by:

$$\lambda_{A23} = \frac{A_{23}^{S}}{R_{2a}\theta_{2a}V_{2a}}$$

where:

$A_{23}^{S}$ is the volume of sub-horizontal flow from the sub-soil compartment of Area 2 to the sub-soil compartment of Area 3 during the summer, $m^3\ y^{-1}$;
$R_{2a}$ is the retardation coefficient for the sub-soil compartment of Area 2;
$\theta_{2a}$ is the water filled porosity of the sub-soil compartment of Area 2;
$V_{2a}$ is the volume of the sub-soil compartment of Area 2, $m^3$.

**Sub-horizontal flow to the surface-soil of Area 3**

The rate of transfer of radionuclides from the sub-soil compartment of Area 2 to the surface soil of Area 3, $\lambda_{A23}$, $y^{-1}$, is given by:

$$\lambda_{A23} = \frac{A_{23}^{W}}{R_{2a}\theta_{2a}V_{2a}}$$

where:

$A_{23}^{W}$ is the volume of sub-horizontal flow from the sub-soil compartment of Area 2 to the surface-soil compartment of Area 3 during the winter, $m^3\ y^{-1}$;
$R_{2a}$ is the retardation coefficient for the sub-soil compartment of Area 2;
$\theta_{2a}$ is the water filled porosity of the sub-soil compartment of Area 2;
$V_{2a}$ is the volume of the sub-soil compartment of Area 2, $m^3$.

*Grassland (Area 3)*

**Groundwater source term to sub-soil compartment**

The radionuclide source term to the sub-soil of Area 3 due to the influx of groundwater, $W_3$, Bq $y^{-1}$, is given by:

$$W_3 = G_3C_g$$

where:

$G_3$ is the volume of groundwater source term to the subsoil of Area 3, $m^3\ y^{-1}$.

**Capillary rise of soil water from the sub-soil to the surface soil**

The transfer of radionuclides from the sub-soil compartment to the surface soil compartment of Area 3 due to capillary rise (and other upward processes), $\lambda_{U3}$, $y^{-1}$, is given by:

$$\lambda_{U3} = \frac{U_3}{R_{3a}\theta_{3a}V_{3a}}$$

where:

$U_3$ is the volume of capillary rise from the sub-soil to the surface soil compartment, $m^3y^{-1}$;
$R_{3a}$ is the retardation coefficient for the sub-soil compartment of Area 3 (defined as for equation 4);
$\theta_{3a}$ is the water filled porosity of the sub-soil compartment of Area 3;
$V_{3a}$ is the volume of the sub-soil compartment of Area 3, $m^3$.

**Transfer of detritus to the local watercourse**

A proportion of the pasture grown on the grassland areas of ERB2B will be lost to the local watercourse due to the movement of detritus. The transfer rate radionuclides from Area 3 to the local watercourse due to the loss of this detritus, $\lambda_{P36}$, $y^{-1}$, is given by:

$$\lambda_{P36} = \frac{P_{36}(CF_{past} + Soil_{past})Y_{past}Area_3}{(1-\theta_{t3b})\rho_{3b}V_{3b}}$$

where:

$P_{36}$ is the fraction of primary productivity in Area 3 lost as detritus to the local watercourse;
$CF_{past}$ is the plant concentration factor from root uptake for the pasture, Bq $kg^{-1}$ (fresh weight crop)/Bq $kg^{-1}$ (dry weight soil);
$Soil_{past}$ is the soil contamination on the pasture, kg (dry weight soil) $kg^{-1}$ (fresh weight crop);
$Y_{past}$ is the above ground fresh weight yield of the plant, kg $m^{-2}$ $y^{-1}$;
$Area_3$ is the area of habitat Area 3, $m^2$;
$\theta_{t3b}$ is the total porosity of the surface soil compartment of Area 3;
$\rho_{3b}$ is the grain density of the surface soil compartment of Area 3, kg $m^{-3}$;
$V_{3b}$ is the volume of the surface soil compartment of Area 3, $m^3$.

**Transfer of manure to the arable area**

The transfer rate radionuclides from Area 3 to the arable areas of ERB2B due to the use of manure as a fertiliser, $\lambda_{M32}$, $y^{-1}$, is given by:

$$\lambda_{M32} = \frac{M_{32}(CF_{past} + Soil_{past})Y_{past}Area_3}{(1-\theta_{t3b})\rho_{3b}V_{3b}}$$

where:

$M_{32}$ is the fraction of pasture primary productivity in Area 3 consumed by cattle and transferred to Area 2 as manure;
$Area_3$ is the area of habitat Area 3, $m^2$;
$\theta_{t3b}$ is the total porosity of the surface soil compartment of Area 3;
$\rho_{3b}$ is the grain density of the surface soil compartment of Area 3, kg $m^{-3}$;
$V_{3b}$ is the volume of the surface soil compartment of Area 3, $m^3$.

The radionuclide concentration of the pasture areas adjacent to the lake will be different from that of the pasture adjacent to the river. The resulting manure generated from each area should be distributed between the arable areas adjacent to the river and lake according the ratio of their areas.

**Transfer of surface soil to the lake due to erosion**

The transfer rate of radionuclides from the surface soil of Area 3 to the local watercourse due to erosion, $\lambda_{E36}$, $y^{-1}$, is given by:

$$\lambda_{E36} = \frac{E_{36}}{V_{3b}}$$

where:

$E_{36}$ is the transfer of surface soil from Area 3 to the local watercourse, $m^3\ y^{-1}$.

**Sub-horizontal flow from the sub-soil**

The rate of transfer of radionuclides from the sub-soil compartment of Area 3 to the surface soil of Area 4, $\lambda_{A34}$, $y^{-1}$, is given by:

$$\lambda_{A34} = \frac{A_{34}}{R_{3a}\theta_{3a}V_{3a}}$$

where:

$A_{34}$ is the volume of sub-horizontal flow from the sub-soil compartment of Area 3, $m^3\ y^{-1}$;
$R_{3a}$ is the retardation coefficient for the sub-surface soil compartment of Area 3;
$\theta_{3a}$ is the water filled porosity of the sub-soil compartment of Area 3;
$V_{3a}$ is the volume of the sub-soil compartment of Area 3, $m^3$.

**Sub-horizontal flow from the surface soil**

The rate of transfer of radionuclides from the surface soil compartment of Area 3 to the local water course, $\lambda_{I36}$, $y^{-1}$, is given by:

$$\lambda_{I34} = \frac{I_{36}}{R_{3b}\theta_{3b}V_{3b}}$$

where:

$I_{36}$ is the volume of sub-horizontal flow from the surface soil compartment of Area 3, $m^3\ y^{-1}$,
$R_{3b}$ is the retardation coefficient for the surface soil compartment of Area 3,
$\theta_{3b}$ is the water filled porosity of the surface soil compartment of Area 3,
$V_{3b}$ is the volume of the surface soil compartment of Area 3, $m^3$.

*Shrubland (Area 4)*

**Groundwater source term to surface soil compartment**

The radionuclide source term to the surface soil of Area 4 due to the influx of groundwater, $W_4$, Bq $y^{-1}$, is given by:

$$W_4 = G_4C_g$$

where:

$G_4$ is the volume of groundwater source term to the surface soil of Area 4, $m^3\ y^{-1}$.

**Transfer of detritus to the local watercourse**

A proportion of the flora growing in the shrubland areas of ERB2B will be lost to the local watercourse due to the movement of detritus. The plant types modelled in the shrubland area are the biomass crops (modelled as other native wild flora), wild fruit, wild nuts and wild fungi.

The radionuclides transferred to the local watercourse due to the movement of contaminated detritus and surface soil are all assumed to become part of the lakebed sediment. The other native flora, fungi, wild fruit and nuts are all assumed to be growing simultaneously on the shrubland area, therefore the transfer rate is the combined total for all four plant types. The transfer rate for radionuclides from Area 4 to the local watercourse due to the loss of this detritus, $\lambda_{P46}$, $y^{-1}$, is given by:

$$\lambda_{P46} = \frac{P_{46}\Sigma_{plants}\left((CF_{plant} + Soil_{plant})Y_{plant}Area_4\right)}{(1-\theta_{t4b})\rho_{4b}V_{4b}}$$

where:

$P_{46}$ is the fraction of primary productivity in Area 4 lost as detritus to the local watercourse;
$Area_4$ is the area of habitat Area 4, $m^2$;
$\theta_{t4b}$ is the total porosity of the surface soil compartment of Area 4;
$\rho_{4b}$ is the grain density of the surface soil compartment of Area 4, kg $m^{-3}$;
$V_{4b}$ is the volume of the surface soil compartment of Area 4, $m^3$.

**Transfer of ash to arable soil**

The transfer rate radionuclides from Area 4 to the surface soil of Area 2 due to the disposal of ash after burning biomass crops (modelled as other native wild flora), $\lambda_{B42}$, $y^{-1}$, is given by:

$$\lambda_{B42} = \frac{B_{42}(CF_{other} + Soil_{other})Y_{other}Area_4}{(1-\theta_{t4b})\rho_{4b}V_{4b}}$$

where:

$B_{42}$ is the fraction of primary productivity in Area 4 cropped and transferred to Area 2 as ash following burning as fuel;
$CF_{other}$ is the crop concentration factor from root uptake for the biomass crop, Bq $kg^{-1}$ (fresh weight crop)/Bq $kg^{-1}$ (dry weight soil);
$Soil_{other}$ is the soil contamination on the biomass crop, kg (dry weight soil) $kg^{-1}$ (fresh weight crop)
$Y_{other}$ is the above ground fresh weight yield of the biomass crop, kg $m^{-2}$ $y^{-1}$;
$Area_4$ is the area of habitat Area 4, $m^2$;
$\theta_{t4b}$ is the total porosity of the surface soil compartment of Area 4;
$\rho_{4b}$ is the grain density of the surface soil compartment of Area 4, kg $m^{-3}$;
$V_{4b}$ is the volume of the surface soil compartment of Area 4, $m^3$.

Note that this makes no allowance for the loss of volatile radionuclides during burning.

The radionuclide concentration of the shrubland areas adjacent to the lake will be different from that of the shrubland adjacent to the river. The resulting ash generated from each area should be distributed between the arable areas adjacent to the river and lake according the ratio of their areas.

**Transfer of surface soil to the local watercourse due to erosion**

The transfer rate of radionuclides from the surface soil of Area 4 to the local watercourse due to erosion, $\lambda_{E46}$, $y^{-1}$, is given by:

$$\lambda_{E46} = \frac{E_{46}}{V_{4b}}$$

where:

$E_{46}$ is the transfer of surface soil from Area 4 to the local watercourse, $m^3\ y^{-1}$.

**Spring flow from the surface soil**

Surface run-off from the shrubland area and wetland areas is assumed to be rapid, therefore it is not explicitly modelled, rather the radionuclide transfers to the surface water are modelled as transferring directly to the local water course. This means that adjacent to the river, the transfers to surface water are taken directly to the river water and adjacent to the lake, the transfers are taken directly to the lake water.

The transfer rate for radionuclides from the surface soil compartment to the local water course, $\lambda_{O4}$, $y^{-1}$, is given by:

$$\lambda_{O4} = \frac{O_4}{R_{4b}\theta_{4b}V_{4b}}$$

where:

$O_4$ is the volume of water moving from the surface soil compartment to the local water course, $m^3\ y^{-1}$;
$R_{4b}$ is the retardation coefficient for the surface soil compartment of Area 4;
$\theta_{4b}$ is the water filled porosity of the surface soil compartment of Area 4;
$V_{4b}$ is the volume of the surface soil compartment of Area 4, $m^3$.

**Sub-horizontal flow from the surface soil**

The rate of transfer of radionuclides from the surface soil compartment of Area 4 to the local water course, $\lambda_{I46}$, $y^{-1}$, is given by:

$$\lambda_{I45} = \frac{I_{46}}{R_{4b}\theta_{4b}V_{4b}}$$

where:

$I_{46}$ is the volume of sub-horizontal flow from the surface soil compartment of Area 4, $m^3\ y^{-1}$;
$R_{4a}$ is the retardation coefficient for the surface soil compartment of Area 4;
$\theta_{4a}$ is the water filled porosity of the surface soil compartment of Area 4;
$V_{4a}$ is the volume of the surface soil compartment of Area 4, $m^3$.

*Wetland (Area 5)*

**Groundwater source term to surface soil compartment**

The radionuclide source term to the surface soil of Area 5 due to the influx of groundwater, $W_5$, Bq y$^{-1}$, is given by:

$$W_5 = G_5 C_g$$

where:

$G_5$ is the volume of groundwater source term to the surface soil of Area 5, m$^3$ y$^{-1}$.

**Transfer of detritus to the local watercourse**

A proportion of the flora growing in the wetland areas of ERB2B will be lost to the local watercourse due to the movement of detritus. The wetland plants are modelled as other native wild flora.

The radionuclides transferred to the lake due to the movement of contaminated detritus and surface soil are all assumed to become part of the surface water compartment of the local watercourse. The transfer rate of radionuclides from Area 5 to the local watercourse due to the loss of this detritus, $\lambda_{P56}$, y$^{-1}$, is given by:

$$\lambda_{P56} = \frac{P_{56}(CF_{other} + Soil_{other})Y_{other}Area_5}{(1-\theta_{t5b})\rho_{5b}V_{5b}}$$

where:

$P_{56}$ is the fraction of primary productivity in Area 5 lost as detritus to the local watercourse;
$CF_{other}$ is the plant concentration factor from root uptake for the wetland plants, Bq kg$^{-1}$ (fresh weight crop)/Bq kg$^{-1}$ (dry weight soil);
$Soil_{other}$ is the *soil* contamination on the wetland plants, kg (dry weight soil) kg$^{-1}$ (fresh weight crop);
$Y_{other}$ is the above ground fresh weight yield of the wetland plants, kg m$^{-2}$ y$^{-1}$;
$Area_5$ is the area of habitat Area 5, m$^2$;
$\theta_{t5b}$ is the total porosity of the surface soil compartment of Area 5;
$\rho_{5b}$ is the grain density of the surface soil compartment of Area 5, kg m$^{-3}$;
$V_{5b}$ is the volume of the surface soil compartment of Area 5, m$^3$.

**Transfer of surface soil to the local watercourse due to erosion**

The transfer rate of radionuclides from the surface soil of Area 5 to the local watercourse due to erosion, $\lambda_{E56}$, y$^{-1}$, is given by:

$$\lambda_{E56} = \frac{E_{56}}{V_{5b}}$$

where:

$E_{5L}$ is the transfer of surface soil from Area 5 to the local watercourse, m$^3$ y$^{-1}$.

**Spring flow from the surface soil**

The transfer rate for radionuclides from the surface soil compartment to the local water course, $\lambda_{O5}$, $y^{-1}$, is given by:

$$\lambda_{O5} = \frac{O_5}{R_{5b}\theta_{5b}V_{5b}}$$

where:

$O_5$ is the volume of water moving from the surface soil compartment to the surface water compartment of Area 5, $m^3$ $y^{-1}$;
$R_{5b}$ is the retardation coefficient for the surface soil compartment of Area 5;
$\theta_{5b}$ is the water filled porosity of the surface soil compartment of Area 5;
$V_{5b}$ is the volume of the surface soil compartment of Area 5, $m^3$.

*River (Area R)*

**Groundwater influx**

The radionuclide source term to the river water due to the influx of groundwater, $W_R$, Bq $y^{-1}$, is given by:

$$W_R = G_R C_g$$

where:

$G_R$ is the volume of groundwater source term to the river water, $m^3$ $y^{-1}$.

It is assumed that the riverbed sediment is in equilibrium with the river water.

**Discharge from the river to the lake**

The transfer rate of radionuclides from the river compartment to the lake, $\lambda_{SRL}$, $y^{-1}$, is given by:

$$\lambda_{SRL} = \frac{S_{RL}}{V_R}$$

where:

$S_{RL}$ is the discharge rate from the river to the lake, $m^3$ $y^{-1}$;'
$V_R$ is the volume of the river compartment, $m^3$.

The riverbed sediment is assumed to be in equilibrium with the river water. Thus the radionuclide concentration, $C_{Rb}$, for radionuclide N, Bq $m^{-3}$, can be calculated using the following equation:

$$C_{Rb} = K_{dRb}\, C_{Rs}\, \rho_{Rb}\theta_{tRb}$$

where:

$K_{dRb}$ is the sorption coefficient of the riverbed sediment, $m^3$ $kg^{-1}$;
$C_{Rs}$ is the radionuclide concentration of the river water compartment, Bq $m^{-3}$;
$\rho_{Rb}$ is the grain density of the riverbed sediment, kg $m^{-3}$;
$\theta_{tRb}$ is the total porosity of the riverbed sediment.

*Lake (Area L)*

**Groundwater influx**

The radionuclide source term to the lakebed sediment due to the influx of groundwater, $W_L$, Bq y$^{-1}$, is given by:

$$W_L = G_L C_g$$

where:

$G_L$ is the volume of groundwater source term to the lakebed sediment, m$^3$ y$^{-1}$.

**Upward movement from sediment to water**

The transfer rate of radionuclides from the sediment to the surface water compartment of the lake, $\lambda_{OL}$, y$^{-1}$, is given by:

$$\lambda_{OL} = \frac{O_L}{R_{Lb}\theta_{Lb}V_{Lb}}$$

where:

$O_L$ is the volume of water moving from the sediment compartment to the surface water compartment of the lake, m$^3$ y$^{-1}$,
$R_{Lb}$ is the retardation coefficient for the sediment compartment of the lake,
$\theta_{Lb}$ is the water filled porosity of the sediment compartment of the lake,
$V_{Lb}$ is the volume of the sediment compartment of the lake, m$^3$.

**Resuspension**

The transfer rate of radionuclides from the sediment compartment to the water compartment of the lake due to resuspension, $\lambda_{rL}$, y$^{-1}$, is given by:

$$\lambda_{rL} = \frac{r_L Area_L}{V_{Lb}\rho_{Lb}(1-\theta_{tLb})}$$

where:

$r_L$ is the resuspension rate of the lakebed sediment, kg m$^{-2}$ y$^{-1}$,
$Area_L$ is the area of the lake, m$^2$

**Sedimentation**

The transfer rate of radionuclides from the surface water compartment of the lake to the sediment compartment of the lake due to sedimentation, $\lambda_{hL}$, y$^{-1}$, is given by:

$$\lambda_{hL} = \frac{K_{dLb}h_L Area_L}{(1+K_{dLb}\alpha_L)V_{Ls}}$$

where:

$h_L$ is the gross sedimentation rate from the water compartment to the associated sediment compartment, kg m$^{-2}$ y$^{-1}$;
$Area_L$ is the area of the lake, m$^2$;
$\alpha_L$ is the suspended sediment load in the surface water compartment of the lake, kg m$^{-3}$;

$V_{Ls}$ is the volume of the surface water compartment of the lake, $m^3$.

**Transfer due to flooding and dredging**

The transfer rate of radionuclides from the sediment of the lake due to flooding and dredging, $\lambda_{FLx}$, $y^{-1}$, is given by:

$$\lambda_{FLx} = \frac{A_x F_{Lx}}{V_{Lb}\rho_{Lb}(1-\theta_{tLb})}$$

where:

$A_x$ is the area of the surface soil compartment to which the transfer occurs, $m^2$;
$F_{Lx}$ is the mass of sediment transferred from the lake to the surface soil compartment of Area x, kg $m^{-2}$ $y^{-1}$.

The lakebed sediment is assumed to be transported to the wetland and shrubland due to flooding and to the arable land as a fertiliser and should be distributed between the areas adjacent to the river and lake according the ratio of their areas.

**Lake discharge**

The transfer rate of radionuclides from the water compartment of the lake due to discharge from the lake, $\lambda_{SL}$, $y^{-1}$, is given by:

$$\lambda_{SL} = \frac{S_L}{V_{Ls}}$$

where:

$S_L$ is the volume of water discharged from the lake, $m^3$ $y^{-1}$;
$V_{Ls}$ is the volume of the surface water compartment of the lake, $m^3$.

### C4.5.5. Dose equations

It is assumed that exposure may originate either adjacent to the river or the lake, and that over time, their contributions will be averaged on the basis of their relative areas. Radionuclide concentrations are therefore averaged across the two cross-sections for each of the land habitats for the exposure calculations.

*Consumption of agricultural crops and wild foodstuffs*

The crops and wild products that may be consumed are green vegetables, root vegetables and grain from the arable areas, fruit, nuts and fungi from the shrubland areas, and other native wild flora from the wetland areas. The annual individual dose from the consumption of these products is given by:

$$D_{crop} = ING_{crop} DC_{ing} C_{crop}$$

where:

$D_{crop}$ is the individual dose from consumption of the crop, Sv $y^{-1}$;
$ING_{crop}$ is the individual ingestion rate of the crop, kg $y^{-1}$;
$DC_{ing}$ is the dose coefficient for ingestion, Sv $Bq^{-1}$;

$C_{crop}$ is the radionuclide concentration in the edible part of the crop, Bq kg$^{-1}$ (fresh weight of crop).

The $C_{crop}$ term is calculated using the following equation:

$$C_{crop} = \frac{(F_{p2}CF_{crop} + F_{p1}Soil_{plant})C_s}{(1-\theta_t)\rho}$$

where:

$F_{p2}$ is the fraction of the internal contamination associated with the edible part of the plant at harvest that is retained after food processing has occurred;
$CF_{crop}$ is the concentration factor from root uptake to the edible portion of the plant, Bq kg$^{-1}$ (fresh weight crop)/Bq kg$^{-1}$ (dry weight soil);
$F_{p1}$ is the fraction of external soil contamination on the edible part of the crop retained after food processing;
$C_s$ is the radionuclide concentration in the soil compartment, Bq kg$^{-1}$.

It should be noted that in calculating $C_{crop}$, the $C_s$, $\theta_t$ and $\rho$ terms refer to the soil properties of the surface soil compartment where the crop plants are growing i.e. for the green vegetables, root vegetables and grain, they refer to the arable surface soil; for the fungi, fruit and nuts they refer to the shrubland soil; and for the other native wild flora they refer to the wetland soil.

The following points should be noted:

— it is assumed that the crop can be contaminated due to:

internal uptake of contaminants from the surface soil compartment into the crop via the roots (represented by the $\frac{CF_{crop}C_s}{(1-\theta_t)\rho}$ term); and

external contamination of the crop due to deposition of re-suspended sediment from the surface soil compartment (represented by the $\frac{Soil_{plant}C_s}{(1-\theta_t)\rho}$ term);

— it is assumed that contamination can be lost due to food preparation (represented by $F_{p1}$ and $F_{p2}$ terms).

*Consumption of animal produce*

Beef and Dairy cattle are assumed to occupy the grassland, wild animals in the shrubland, wild birds in the wetland, and fish are assumed to occupy the lake. The annual individual dose from the consumption of animal produce is given by:

$$D_{prod} = ING_{prod}DC_{ing}C_{prod}$$

where:

$D_{prod}$ is the individual dose from consumption of the animal product, Sv y$^{-1}$;
$ING_{prod}$ is the individual consumption rate of the animal product, kg y$^{-1}$;
$C_{prod}$ is the radionuclide concentration in the animal product, Bq kg$^{-1}$.

The $C_{prod}$ term is calculated using the following equation:

$$C_{prod} = TF_{proding}\left( C_{fodd} ING_{fodd} + C_{Ls} ING_{wa} + \frac{C_s \ \ ING_{sa}}{(1-\theta_t)\rho + \theta\rho_w} \right) + (BR_a O_{an} C_{airs}) TF_{prodinh}$$

where:

$TF_{proding}$ is the *transfer* factor for ingestion for the animal product, d kg$^{-1}$ (fresh weight of product);

$C_{fodd}$ is the radionuclide concentration in the animal fodder, Bq kg$^{-1}$ (fresh weight of fodder);

$TF_{prodinh}$ is the *transfer* factor for inhalation for the animal product, d kg$^{-1}$ (fresh weight of product);

$ING_{fodd}$ is the consumption rate of fodder by the animal, kg (fresh weight) d$^{-1}$;

$C_{Ls}$ is the radionuclide concentration in the lake water, Bq m$^{-3}$;

$ING_{wa}$ is the consumption rate of water by the animal, m$^3$ d$^{-1}$, all animals are assumed to obtain their water from the lake;

$ING_{sa}$ is the consumption rate of soil from the cultivated soil compartment by the animal, kg (wet weight of soil) d$^{-1}$;

$\rho_w$ is the density of water, kg m$^{-3}$;

$BR_a$ is the breathing rate of the animal, m$^3$ h$^{-1}$;

$O_{an}$ is the occupancy time of the animal in the cultivated soil compartment, h d$^{-1}$;

$C_{airs}$ is the radionuclide concentration in the air above the cultivated soil compartment, Bq m$^{-3}$.

In calculating $C_{prod}$, the $C_s$, $\theta_t$ and $\rho$ terms refer to the soil properties of the surface soil compartment where the animals are feeding i.e. for cattle they refer to the pasture surface soil; for the wild animals they refer to the shrubland soil; and for the wild birds they refer to the wetland soil.

It is assumed that the animal can be contaminated due to:

— consumption of contaminated fodder (represented by the Cfodd INGfodd term);

— consumption of contaminated water (represented by the Cw INGwa term);

— consumption of contaminated soil (represented by the $\frac{C_s ING_{sa}}{(1-\theta_t)\rho + \theta\rho_w}$ term); and

— inhalation of contaminated soil (represented by the BRa Oan Cairs term).

The $C_{airs}$ term is calculated using the following equation:

$$C_{airs} = \frac{C_s}{(1-\theta_t)\rho} \frac{(R-1)}{R} dust_s$$

where:

$dust_s$ is the soil derived dust level in the air above the cultivated soil compartment (the animals are assumed to be exposed to normal dust loading), kg m$^{-3}$.

In calculating $C_{airs}$, the $C_s$, $\theta_t$ and $\rho$ terms refer to the soil properties of the surface soil compartment where the animals are breathing i.e. for the cattle they refer to the grassland surface soil; for the wild animals they refer to the shrubland surface soil; and for the wild birds the $BR_a$ $O_{an}$ $C_{airs}$ term should be calculated for both the contribution from the wetland soil and the shrubland soil according to the occupancy of each area.

The nature of the fodder consumed by the animal depends on the type of animal. It is assumed that the cows consume pasture from the grassland areas, the wild animals consume other native wild flora from the shrubland areas and the wild birds consume other native wild flora from the wetland areas. The $C_{fodd}$ term is calculated using the following equation:

$$C_{fodd} = \frac{(CF_{plant} + Soil_{plant})C_s}{(1-\theta_t)\rho}$$

In calculating $C_{fodd}$, the $C_s$, $\theta_t$ and $\rho$ terms refer to the soil properties of the surface soil compartment where the animals are feeding i.e. for the cattle they refer to the grassland surface soil; for the wild animals they refer to the shrubland surface soil; and for the wild birds they refer to the wetland soil.

The $TF_{prodinh}$ term is calculated using the following equation:

$$TF_{prodinh} = TF_{proding} \frac{f_L + f_C\, f_1(inh)}{f_1(ing)}$$

where:

$f_L$ is the fraction of inhaled activity reaching the systemic circulation of man following transfer across the lung lining;
$f_C$ is the fraction of inhaled activity that is cleared to the gastrointestinal tract of man;
$f_1(inh)$ is the fraction of inhaled activity, cleared to the gastrointestinal tract, that is transferred to the systemic circulation of man;
$f_1(ing)$ is the fraction of ingested activity reaching the body fluids in man.

*Consumption of fish*

The annual individual dose from the consumption of fish from the lake is given by:

$$D_{aqfood} = ING_{aqfood} DC_{ing} C_{aqfood}$$

where:

$D_{aqfood}$ is the *individual* dose from consumption of the aquatic foodstuff, Sv $y^{-1}$;
$ING_{aqfood}$ is the *individual* consumption rate of the aquatic foodstuff, kg $y^{-1}$;
$C_{aqfood}$ is the radionuclide concentration of the aquatic food, Bq $kg^{-1}$.

The $C_{aqfood}$ term is calculated using the following equation:

$$C_{aqfood} = FF_{6s} C_{Ls} CF_{aqfood}$$

where:

$FF_{6s}$ is the fraction of activity in the filtered lake water;
$C_{Ls}$ is the radionuclide concentration in the surface water of the lake, Bq $m^{-3}$;
$CF_{aqfood}$ is the concentration factor for the aquatic foodstuff, Bq $kg^{-1}$ (fresh weight of edible fraction)/Bq $m^{-3}$ (filtered water).

The $FF_{6s}$ term is calculated using the following equation:

$$FF_{6s} = \frac{1}{1 + K_{d6b}\alpha_{6s}}$$

where:

$K_{d6b}$ is the sorption coefficient for the lakebed sediment, $m^3\ kg^{-1}$.

*Consumption of soil*

Apart from inadvertent consumption due to soil contamination of crops, soil can be consumed by humans both inadvertently and deliberately. The annual individual dose from this type of soil consumption is given by:

$$D_{soil} = ING_{soil} DC_{ing} \frac{C_s}{(1-\theta_t)\rho + \theta\rho_w}$$

where:

$D_{soil}$ is the individual dose from consumption of soil, $Sv\ y^{-1}$;
$ING_{soil}$ is the individual consumption rate of the soil, $kg\ y^{-1}$, wet weight.

In calculating $D_{soil}$, the $C_s$, $\theta_t$ and $\rho$ terms refer to the soil properties of the surface soil compartment from where the soil originates.

*External irradiation from the soil*

The annual individual dose from external irradiation from soil/sediment, during occupancy of the soil compartment, is given by:

$$D_{exsoil} = O_s DC_{exts} C_s$$

where:

$D_{exsoil}$ is the individual dose from external irradiation from the soil, $Sv\ y^{-1}$;
$O_s$ is the individual occupancy in the soil compartment, $h\ y^{-1}$;
$DC_{exts}$ is the dose factor for external irradiation from soil, $Sv\ h^{-1}/Bq\ m^{-3}$.

It is assumed that external exposure during periods of occupancy of the river and lake is dominated by exposure from the sediments at the river and lake margins. Therefore, external exposure within these areas is calculated as exposure to these sediments. The $C_s$ term refers to the radionuclide concentration of the soil where the occupancy occurs.

*External irradiation from immersion in water*

It is assumed that whilst swimming in the lake, exposure is due to immersion in the water alone and not from external irradiation from the lakebed sediment. The annual individual dose from external irradiation from immersion in water is given by:

$$D_{imwat} = O_{wat} DC_{imw} C_{Ls}$$

where:

$D_{imwat}$ is the individual dose from external irradiation from immersion in the water, $Sv\ y^{-1}$;
$O_{wat}$ is the individual occupancy in the water, $h\ y^{-1}$;
$DC_{imw}$ is the dose coefficient for external irradiation from immersion in water, $Sv\ h^{-1}$ / $Bq\ m^{-3}$.

*Inhalation of dust*

The annual individual dose from the inhalation of dust, during occupancy of the soil compartment, is calculated for both normal and dusty conditions using:

$$D_{dust} = DC_{inh} BR\, O_s C_{airs}$$

where:

$D_{dust}$ is the individual dose from the inhalation of dust, Sv $y^{-1}$;
$DC_{inh}$ is the dose coefficient for inhalation, Sv $Bq^{-1}$;
$BR$ is the breathing rate of the human in the soil compartment, $m^3$ $h^{-1}$.

Where inhalation of dust may occur under different conditions within the same habitat area, e.g. exposure during periods of high and normal dust loading within the arable areas of Example 2B, then the exposures are calculated separately.

*Inhalation of spray*

The annual individual dose from the inhalation of aerosols in water spray is given by:

$$D_{aero} = DC_{inh} BR\ AIR_{aero} O_{aero} C_{6s}$$

where:

$D_{aero}$ is the individual dose from the inhalation of aerosols, Sv $y^{-1}$;
$AIR_{aero}$ is the aerosol level in the air in the area affected by aerosols/spray, $m^3$ $m^{-3}$;
$O_{aero}$ is the individual occupancy in the area affected by aerosols, h $y^{-1}$;
$C_{6s}$ is the radionuclide concentration of the surface water compartment, this may either be the river or the lake, depending on where the exposure originates, Bq $m^{-3}$.

## C4.6. SELECTION OF DATA FOR ERB2B

Table C53 lists the element, area and exposure group independent data. Tables C54–C57 list the radionuclide and element dependent data. Tables C58 and C59 list the exposure group dependent data. Tables C60–C65 list the habitat dependent data. Table C66 lists the water flow rates between compartments calculated separately. Table C67 lists the derived transfer rates of plant and soil material between habitat areas.

TABLE C53. ELEMENT, AREA AND EXPOSURE GROUP INDEPENDENT DATA

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Crop soil contamination, $Soil_{crop}$ | | kg (dw soil) $kg^{-1}$ (fw crop) | |
| – Green vegetables | 2.0E-4 | | |
| – Root vegetables | 2.0E-4 | | Chosen from consideration of data in BIOMOVS II (1996), Müller and Pröhl (1993), |
| – Grain | 2.0E-4 | | Ashton and Sumerling (1988), Smith et al., (1996) and Brown and Simmonds (1995). |
| – Pasture | 2.0E-3 | | |
| – Wild fungi | 2.0E-4 | | Assume the same as for crops. |
| – Wild fruit | 2.0E-4 | | Assume the same as for crops. |
| – Wild nuts | 0.0E0 | | Assumed not to consume the shells. |
| – Other native wild flora and products | 2.0E-4 | | Assume the same as for crops. |
| Crop annual yield, $Y_{plant}$ | | kg fw $m^{-2}$ $y^{-1}$ | Yield of above ground biomass for use in the calculation of detritus movement. |
| – Green vegetables | 3.0E0 | | |
| – Root vegetables | 3.0E0 | | Chosen from consideration of data in BIOMOVS II (1996), Müller and Pröhl (1993), |
| – Grain | 3.0E0 | | Ashton and Sumerling (1988), Smith et al., (1996) and Brown and Simmonds (1995). |
| – Pasture | 5.0E0 | | |
| – Wild fungi | 9.0E-2 | | Based on that for fruit. |
| – Wild fruit | 9.0E-2 | | Approximately a tenth that recorded in Brown and Simmonds (1995), assuming that the available data is for commercial fruit production. |
| – Wild nuts | 9.0E-2 | | Based on that for fruit. |
| – Other native wild flora | 2.5E0 | | Data chosen for leafy vegetables, Jackson (1984) in Ashton and Sumerling (1988). |
| External fraction retained after food processing, $F_{p1}$ | | – | |
| – Green vegetables | 1.0E-1 | | Green and Wilkins (1995). |
| – Root vegetables | 1.0E-1 | | Green and Wilkins (1995). |
| – Grain | 1.0E-1 | | Green and Wilkins (1995). |
| – Wild fungi | 1.0E-1 | | Assumed the same as for crops. |
| – Wild fruit | 1.0E-1 | | Assumed the same as for crops. |
| – Wild nuts | 0.0E0 | | Assumed not to consume the shell. |
| – Other native wild flora and products | 1.0E-1 | | Assumed the same as for crops. |
| Internal fraction retained after food processing, $F_{p2}$ | 1.0E0 | – | NRPB guidance in Green and Wilkins (1995), cautious but not very. |
| Animal fodder consumption rate, $ING_{fodd}$ | | kg (fw) $d^{-1}$ | |
| – cattle | 7.0E1 | | Based on dairy cattle, IAEA (1994). |
| – wild animals | 7.0E0 | | Based on sheep, IAEA (1994). |
| – wild birds | 3.0E-1 | | Based on hens, IAEA (1994). |

TABLE C53. ELEMENT, AREA AND EXPOSURE GROUP INDEPENDENT DATA (CONTINUED)

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Animal water consumption rate, $ING_{wa}$ | | $m^3 d^{-1}$ | |
| – Cattle | 7.0E-2 | | Based on dairy cattle, IAEA (1994). |
| – Wild animals | 5.0E-3 | | Data for sheep used, IAEA (1994) |
| – Wild birds | 1.0E-4 | | Data for chicken used, IAEA (1994). |
| Animal soil consumption rate, $ING_{sa}$ | | kg (wet soil) $d^{-1}$ | |
| – Cattle | 6.0E-1 | | Based on dairy cattle, IAEA (1994). |
| – Wild animals | 1.5E-1 | | Based on sheep, IAEA (1994). |
| – Wild birds | 3.0E-2 | | Based on data for chicken, Thorne (1984) in Ashton and Sumerling (1988). |
| Water density, $\rho_w$ | 1.0E3 | kg $m^{-3}$ | Lide (2000). |
| Animal breathing rate, $BR_a$ | | $m^3 h^{-1}$ | |
| – Cattle | 5.4E0 | | Brown and Simmonds (1995). |
| – Wild animals | 3.6E-1 | | Data for sheep used, Brown and Simmonds (1995). |
| – Wild birds | 1.0E-2 | | Data for chicken used, Smith et al., (1996). |
| Human breathing rate, BR | | $m^3 h^{-1}$ | |
| – Adult, normal activity | 1.2E0 | | |
| – Adult, physical working | 1.7E0 | | BIOMASS (2001). |
| – Infant | 2.2E-1 | | |

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TABLE C54. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, I-129

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Concentration in aquifer, $C_g$ | 1.0E0 | Bq m$^{-3}$ | Prescribed in the assessment context. |
| Decay constant, $\lambda$ | 4.4E-8 | y$^{-1}$ | ICRP (1983). |
| Sorption coefficient, $K_d$ | | m$^3$ kg$^{-1}$ | |
| – Arable land subsoil, 2a | 1.0E-2 | | |
| – Arable land surface soil, 2b | 1.0E-2 | | IAEA (1994) – data for R are more relevant here, so a $K_d$ was chosen give a residence time in the soil of about 200 y. |
| – Grassland subsoil, 3a | 1.0E-2 | | |
| – Grassland surface soil, 3b | 1.0E-2 | | |
| – Shrubland surface soil, 4b | 2.7E-2 | | IAEA (1994) data for organic soil. |
| – Wetland surface soil, 5b | 2.7E-2 | | IAEA (1994) data for organic soil. |
| – Riverbed sediment, Rb | 3.0E-1 | | Kane (1984) in Ashton and Sumerling (1988). |
| – Lakebed sediment, Lb | 3.0E-1 | | Kane (1984) in Ashton and Sumerling (1988). |
| Plant concentration factor, $CF_{plant}$ | | Bq kg$^{-1}$ (fw)/ Bq kg$^{-1}$ (dw) | i.e. concentration factor to the above ground plant parts that may be lost as detritus. |
| – Green vegetables | 3E-3 | | |
| – Root vegetables | 3E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000). |
| – Grain | 3E-3 | | |
| – Pasture | 3E-3 | | |
| – Wild fungi | 3.4E-3 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 4E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for herbaceous fruit. |
| – Wild nuts | 4E-2 | | Based on that for fruit. |
| – Other native wild flora and products | 2.5E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |
| Crop concentration factor, $CF_{crop}$ | | Bq kg$^{-1}$ (fw)/ Bq kg$^{-1}$ (dw) | i.e. concentration factor to the cropped portion of the plant. |
| – Green vegetables | 3E-3 | | |
| – Root vegetables | 3E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000). |
| – Grain | 3E-3 | | |
| – Wild fungi | 3.4E-3 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 4E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for herbaceous fruit. |
| – Wild nuts | 4E-2 | | Based on that for fruit. |
| – Other native wild flora and products | 2.5E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |

TABLE C54. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, I-129 (CONTINUED)

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.1E-7 | | IAEA (1996). |
| – Infant | 1.8E-7 | | IAEA (1996). |
| Transfer factor to animal product from ingestion, $TF_{proding}$ | | d $kg^{-1}$ or d $l^{-1}$ | |
| – Cattle meat | 3.0E-3 | | Smith et al., (1996) data for cows. |
| – Cattle offal | 3.0E-3 | | NRPB (1996) used in calculating generalised derived limits. |
| – Cows milk | 3.0E-3 | | Smith et al., (1996). |
| – Wild animal meat | 5.0E-2 | | Data for sheep used, NRPB (1996). |
| – Wild bird meat | 2.0E-1 | | Data for chicken used, Coughtrey (1990). |
| Fraction of ingested activity reaching the body fluid of man, $f_1$(ing) | 1.0E0 | | ICRP (1996). |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 5.0E-1 | – | Coughtrey et al., (1983) – inhalation class D, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 1.6E-1 | – | Coughtrey et al., (1983) – inhalation class D, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1$(inh) | 1.0E0 | – | ICRP (1996) – inhalation class F. |
| Aquatic foodstuff concentration factor, $CF_{aqfood}$ | | Bq $kg^{-1}$/Bq $m^{-3}$ | |
| – fish | 3.0E-2 | | Coughtrey et al., (1983). |
| External dose factor, $DC_{exts}$ | 2.5E-16 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| External dose factor due to immersion in water, $DC_{imw}$ | 3.2E-15 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 3.6E-8 | | IAEA (1996). |
| – Infant | 7.2E-8 | | IAEA (1996). |

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TABLE C55. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Tc-99

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Concentration in aquifer, $C_g$ | 1.0E0 | Bq $m^{-3}$ | Prescribed in the assessment context. |
| Decay constant, $\lambda$ | 3.3E-6 | $y^{-1}$ | ICRP (1983). |
| Sorption coefficient, $K_d$ | | $m^3$ $kg^{-1}$ | |
| – Arable land subsoil, 2a | 1.7E-5 | | Coughtrey et al., (1983). |
| – Arable land surface soil, 2b | 1.7E-5 | | |
| – Grassland subsoil, 3a | 1.7E-5 | | |
| – Grassland surface soil, 3b | 1.7E-5 | | |
| – Shrubland surface soil, 4b | 1.5E-3 | | IAEA (1994) for organic soil. |
| – Wetland surface soil, 5b | 1.5E-3 | | IAEA (1994) for organic soil. |
| – Riverbed sediment, Rb | 1.0E-2 | | Kane (1984) in Ashton and Sumerling (1988). |
| – Lakebed sediment, Lb | 1.0E-2 | | Kane (1984) in Ashton and Sumerling (1988). |
| Plant concentration factor, $CF_{plant}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the above ground plant parts that may be lost as detritus. |
| – Green vegetables | 1.0E1 | | From consideration of IAEA (1994). |
| – Root vegetables | 1.0E1 | | |
| – Grain | 1.0E1 | | |
| – Pasture | 1.0E1 | | |
| – Wild fungi | 7.8E2 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 1.8E1 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 1.8E1 | | Based on that for fruit. |
| – Other native wild flora and products | 3.6E1 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the cropped portion of the plant. |
| – Green vegetables | 1.0E1 | | From consideration of IAEA (1994) and Coughtrey et al., (1983). |
| – Root vegetables | 1.0E1 | | |
| – Grain | 1.0E1 | | |
| – Wild fungi | 7.8E2 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 1.8E1 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 1.8E1 | | Based on that for fruit. |
| – Other native wild flora and products | 3.6E1 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |

# TABLE C55. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Tc-99 (CONTINUED)

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Ingestion dose coefficient, $DC_{ing}$ | | $Sv\ Bq^{-1}$ | |
| – Adult | 6.4E-10 | | IAEA (1996). |
| – Infant | 1.0E-8 | | IAEA (1996). |
| Transfer factor to animal product from ingestion, $TF_{proding}$ | | $d\ kg^{-1}$ or $d\ l^{-1}$ | |
| – Cattle meat | 6.0E-3 | | Smith et al., (1996). |
| – Cattle offal | 2.1E-3 | | Smith et al., (1996) for cattle liver, from consideration of range. |
| – Cows milk | 7.5E-3 | | Smith et al., (1996). |
| – Wild animal meat | 8.6E-2 | | Data for sheep used, Thorne (1984) in Ashton and Sumerling (1988). |
| – Wild bird meat | 1.2E0 | | Data for chicken used, Thorne (1984) in Ashton and Sumerling (1988). |
| Fraction of ingested activity reaching the body fluid of man, $f_1$(ing) | 5.0E-1 | | ICRP (1996). |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1$(inh) | 1.0E-1 | – | ICRP (1996) – inhalation class M. |
| Aquatic foodstuff concentration factor, $CF_{aqfood}$ | | $Bq\ kg^{-1}/Bq\ m^{-3}$ | |
| – Fish | 1.5E-2 | | Coughtrey et al., (1983). |
| External dose factor, $DC_{exts}$ | 2.4E-18 | $Sv\ h^{-1}/Bq\ m^{-3}$ | Eckerman and Ryman (1993). |
| External dose factor due to immersion in water, $DC_{imw}$ | 1.1E-17 | $Sv\ h^{-1}/Bq\ m^{-3}$ | Eckerman and Ryman (1993). |
| Inhalation dose coefficient, $DC_{inh}$ | | $Sv\ Bq^{-1}$ | |
| – Adult | 1.3E-8 | | IAEA (1996). |
| – Infant | 4.1E-8 | | IAEA (1996). |

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TABLE C56. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Np-237

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Concentration in aquifer, $C_g$ | 1.0E0 | Bq $m^{-3}$ | Prescribed in the assessment context. |
| Decay constant, $\lambda$ | 3.2E-7 | $y^{-1}$ | ICRP (1983). |
| Sorption coefficient, $K_d$ | | $m^3$ $kg^{-1}$ | |
| – Arable land subsoil, 2a | 3.0E-2 | | |
| – Arable land surface soil, 2b | 3.0E-2 | | Coughtrey et al., (1983). |
| – Grassland subsoil, 3a | 3.0E-2 | | |
| – Grassland surface soil, 3b | 3.0E-2 | | |
| – Shrubland surface soil, 4b | 1.2E0 | | IAEA (1994) for organic soil. |
| – Wetland surface soil, 5b | 1.2E0 | | IAEA (1994) for organic soil. |
| – Riverbed sediment, Rb | 5.0E-1 | | Kane (1984) in Ashton and Sumerling (1988). |
| – Lakebed sediment, Lb | 5.0E-1 | | Kane (1984) in Ashton and Sumerling (1988). |
| Plant concentration factor, $CF_{plant}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the above ground plant parts that may be lost as detritus. |
| – Green vegetables | 5.0E-3 | | |
| – Root vegetables | 5.0E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000). |
| – Grain | 5.0E-3 | | |
| – Pasture | 5.0E-3 | | |
| – Wild fungi | 5.7E-2 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 2.8E-4 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 2.8E-4 | | Based on that for fruit |
| – Other native wild flora and products | 5.3E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the cropped portion of the plant. |
| – Green vegetables | 5.0E-3 | | |
| – Root vegetables | 5.0E-3 | | From consideration of IAEA (1994) and Koch-Steindl and Pröhl (2000). |
| – Grain | 2.0E-3 | | |
| – Wild fungi | 5.7E-2 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 2.8E-4 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 2.8E-4 | | Based on that for fruit. |
| – Other native wild flora and products | 5.3E-2 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |

TABLE C56. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Np-237 (CONTINUED)

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.1E-7 | | IAEA (1996). |
| – Infant | 2.0E-6 | | IAEA (1996). |
| Transfer factor to animal product from ingestion, $TF_{proding}$ | | d $kg^{-1}$ or d $l^{-1}$ | |
| – Cattle meat | 1.0E-4 | | Smith et al., (1996). |
| – Cattle offal | 1.0E-4 | | Smith et al., (1996) from consideration of range. |
| – Cows milk | 1.0E-4 | | Smith et al., (1996) from consideration of range. |
| – Wild animal meat | 1.4E-4 | | Data for sheep used, Thorne (1984) in Ashton and Sumerling (1988). |
| – Wild bird meat | 1.7E-3 | | Data for chicken used, Thorne (1984) in Ashton and Sumerling (1988). |
| Fraction of ingested activity reaching the body fluid of man, $f_1$(ing) | 5.0E-4 | | ICRP (1996). |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1$(inh) | 5.0E-4 | – | ICRP (1996) – inhalation class M. |
| Aquatic foodstuff concentration factor, $CF_{aqfood}$ | | Bq $kg^{-1}$/Bq $m^{-3}$ | |
| – Fish | 1.0E-2 | | IAEA (1982). |
| External dose factor, $DC_{exts}$ | 1.5E-15 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| External dose factor due to immersion in water, $DC_{imw}$ | 8.4E-15 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 5.0E-5 | | IAEA (1996). |
| – Infant | 9.8E-5 | | IAEA (1996). |

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TABLE C57. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Nb-94

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Concentration in aquifer, $C_g$ | 1.0E0 | Bq $m^{-3}$ | Prescribed in the assessment context. |
| Decay constant, $\lambda$ | 3.4E-5 | $y^{-1}$ | ICRP (1983). |
| Sorption coefficient, $K_d$ | | $m^3$ $kg^{-1}$ | |
| – Arable land subsoil, 2a | 9.0E-1 | | |
| – Arable land surface soil, 2b | 9.0E-1 | | From consideration of IAEA (1994). |
| – Grassland subsoil, 3a | 9.0E-1 | | |
| – Grassland surface soil, 3b | 9.0E-1 | | |
| – Shrubland surface soil, 4b | 2.0E0 | | IAEA (1994) for organic soils. |
| – Wetland surface soil, 5b | 2.0E0 | | IAEA (1994) for organic soils. |
| – Riverbed sediment, Rb | 1.0E1 | | Kane (1984) in Ashton and Sumerling (1988). |
| – Lakebed sediment, Lb | 1.0E1 | | Kane (1984) in Ashton and Sumerling (1988). |
| Plant concentration factor, $CF_{plant}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the above ground plant parts that may be lost as detritus. |
| – Green vegetables | 4.0E-4 | | |
| – Root vegetables | 4.0E-4 | | Derived from Coughtrey et al., (1983). |
| – Grain | 4.0E-4 | | |
| – Pasture | 4.0E-4 | | |
| – Wild fungi | 5.0E-3 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 2.5E-3 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 2.5E-3 | | Based on that for fruit. |
| – Other native wild flora and products | 5.0E-3 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |
| Crop concentration factor, $CF_{crop}$ | | Bq $kg^{-1}$ (fw)/ Bq $kg^{-1}$ (dw) | i.e. concentration factor to the cropped portion of the plant. |
| – Green vegetables | 4.0E-4 | | |
| – Root vegetables | 2.5E-3 | | Derived from Coughtrey et al., (1983). |
| – Grain | 1.6E-3 | | |
| – Wild fungi | 5.0E-3 | | Highest value for plant uptake used from IAEA (1994), divided by 10 to convert to approximate fresh weight CF. |
| – Wild fruit | 2.5E-3 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988). |
| – Wild nuts | 2.5E-3 | | Based on that for fruit. |
| – Other native wild flora and products | 5.0E-3 | | Mitchell and Jones (1987) in Ashton and Sumerling (1988) for non-leguminous leafy vegetables. |

TABLE C57. ELEMENT OR RADIONUCLIDE DEPENDENT DATA, Nb-94 (CONTINUED)

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Ingestion dose coefficient, $DC_{ing}$ | | Sv $Bq^{-1}$ | |
| – Adult | 1.7E-9 | | IAEA (1996). |
| – Infant | 1.5E-8 | | IAEA (1996). |
| Transfer factor to animal product from ingestion, $TF_{proding}$ | | d $kg^{-1}$ or d $l^{-1}$ | |
| – Cattle meat | 1.7E-4 | | Thorne (1984) in Ashton and Sumerling (1988). |
| – Cattle offal | 2.1E-3 | | Thorne (1984) in Ashton and Sumerling (1988) for kidney. |
| – Cows milk | 4.0E-7 | | IAEA (1994). |
| – Wild animal meat | 1.6E-3 | | Data for sheep used, Thorne (1984) in Ashton and Sumerling (1988). |
| – Wild bird meat | 2.2E-2 | | Data for chicken used, Thorne (1984) in Ashton and Sumerling (1988). |
| Fraction of ingested activity reaching the body fluid of man, $f_1$(ing) | 1.0E-2 | | ICRP (1996). |
| Fraction of inhaled activity reaching body fluids of man across lung lining, $f_L$ | 1.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity cleared to the lung of man, $f_C$ | 5.5E-1 | – | Coughtrey et al., (1983) – inhalation class W, activity mean aerodynamic diameter 1E-6 m. |
| Fraction of inhaled activity, cleared to the gut, that is absorbed to the body fluids of man, $f_1$(inh) | 1.0E-2 | – | ICRP (1996) – inhalation class M. |
| Aquatic foodstuff concentration factor, $CF_{aqfood}$ | | Bq $kg^{-1}$/Bq $m^{-3}$ | |
| – Fish | 3.0E-1 | | IAEA (1982). |
| External dose factor, $DC_{exts}$ | 1.9E-13 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| External dose factor due to immersion in water, $DC_{imw}$ | 6.0E-13 | Sv $h^{-1}$/Bq $m^{-3}$ | Eckerman and Ryman (1993). |
| Inhalation dose coefficient, $DC_{inh}$ | | Sv $Bq^{-1}$ | |
| – Adult | 9.9E-8 | | IAEA (1996). |
| – Infant | 1.2E-7 | | IAEA (1996). |

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TABLE C58. EXPOSURE GROUP CONSUMPTION RATES (kg fresh weight $y^{-1}$)

| Consumption Category | Exposure Group | | | | | | | Source |
|---|---|---|---|---|---|---|---|---|
| | Arable Farmer | Livestock Farmer | Horticultural Producer | Gamekeeper | Fisherman | Villager | Infant | |
| Green vegetables | 49.5 | 49.5 | 148.5 | 49.5 | 49.5 | 49.5 | 29 | Arable land |
| Root vegetables | 316.5 | 105.5 | 316.5 | 105.5 | 105.5 | 105.5 | 51.6 | |
| Grain | 471 | 157 | 157 | 157 | 157 | 157 | 14.8 | |
| Wild fungi [c] | 6 | 6 | 6 | 18 | 6 | 6 | 3 | Shrubland |
| Wild fruit [c] | 45 | 45 | 45 | 135 | 45 | 45 | 33.6 | |
| Wild nuts [c] | 1.5 | 1.5 | 1.5 | 10 | 1.5 | 1.5 | 1 | |
| Other native flora | 1.5 | 1.5 | 1.5 | 10 | 1.5 | 1.5 | 1 | Wetland |
| Cattle meat | 69.3 | 207.9 | 69.3 | 69.3 | 69.3 | 69.3 | 29.5 | Grassland |
| Cattle offal | 4.5 | 13.5 | 4.5 | 4.5 | 4.5 | 4.5 | 0.6 | |
| Cows milk | 248 | 744 | 248 | 248 | 248 | 248 | 159.9 | |
| Wild animal meat [a] | 8.75 | 8.75 | 8.75 | 25 | 8.75 | 8.75 | 4.5 | Shrubland |
| Wild bird meat [a] | 8.75 | 8.75 | 8.75 | 25 | 8.75 | 8.75 | 4.5 | Wetland |
| Fish [b] | 2.3 | 2.3 | 2.3 | 2.3 | 6.9 | 2.3 | 0.0 | Lake |
| Soil | | | | | | | | |
| – Arable land soil | 0.0055 | | 0.0025 | | | 0.0025 | 0.037 | Arable land |
| – Pasture land soil | | 0.0055 | | | | | | Grassland |
| – shrubland soil | 0.0015 | 0.0015 | 0.0007 | 0.0021 | 0.0007 | 0.0007 | | Shrubland |
| – Wetland soil | 0.0010 | 0.0010 | 0.0004 | 0.0014 | 0.0004 | 0.0004 | | Wetland |
| – River sediment | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | | River |
| – Lake sediment | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0025 | 0.0001 | | Lake |

Consumption rates for farm produce are as for ERB2A

[a]median consumption for data presented by Green et al., (1999) for consumption of rabbit, assuming average of 0.5kg of meat per animal, and critical is three times the median. The same value is assumed for wild bird meat.

[b] fish and shellfish combined.

[c] Skuterud et al., (1999) for average, and critical is three times the average.

TABLE C59. EXPOSURE GROUP OCCUPANCY RATES (h $y^{-1}$)

| Category | Source | Exposure Group: Arable Farmer | Livestock Farmer | Horticultural Producer | Gamekeeper | Fisherman | Villager | Infant |
|---|---|---|---|---|---|---|---|---|
| Normal breathing rate, normal atmospheric dust loading | Arable | 2472 | | 2472 | | | 2919 | 4383 |
| | Pasture | | 2586 | | | | | |
| | Shrubland | 777 | 777 | 777 | 2530 | 777 | 777 | |
| | Wetland | 516 | 516 | 516 | 1682 | 516 | 516 | |
| | River | 81 | 81 | 81 | 81 | 81 | 81 | |
| | Lake | 88 | 88 | 88 | 88 | 3007 | 88 | |
| High breathing rate, high atmospheric dust loading | Arable | 448 | | 448 | | | | |
| | Pasture | | 336 | | | | | |
| | Shrubland | | | | | | | |
| | Wetland | | | | | | | |
| | River | | | | | | | |
| | Lake | | | | | | | |
| Total occupancy for each habitat area | Arable | 2920 | | 2920 | | | 2919 | 4383 |
| | Pasture | | 2922 | | | | | |
| | Shrubland | 777 | 777 | 777 | 2530 | 777 | 777 | |
| | Wetland | 516 | 516 | 516 | 1682 | 516 | 516 | |
| | River | 81 | 81 | 81 | 81 | 81 | 81 | |
| | Lake | 88 | 88 | 88 | 88 | 3007 | 88 | |
| Total occupancy | | 4381 | 4383 | 4381 | 4380 | 4380 | 4380 | 4383 |
| Swimming | Lake | 25 | 25 | 25 | 25 | 100 | 25 | |

Note: Occupancy for external irradiation for soil and inhalation of dust does not include domestic and sleeping occupancy.

TABLE C60. HABITAT DEPENDENT DATA, ARABLE LAND

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area adjacent to the lake, $Area_x$ | 5.0E5 | $m^2$ | |
| Area adjacent to the river, $Area_x$ | 6.6E5 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Subsoil, 2a | 1.6E0 | | |
| – Surface soil, 2b | 4.0E-1 | | |
| Wet soil porosity, $\theta$ | | – | |
| – Subsoil, 2a | 3.0E-1 | | Higher than the surface soil. |
| – Surface soil, 2b | 2.0E-1 | | As for Example 2A. |
| Total soil porosity, $\theta_t$ | | – | |
| – Subsoil, 2a | 5.0E-1 | | As for Example 2A. |
| – Surface soil, 2b | 5.0E-1 | | As for Example 2A. |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Subsoil, 2a | 2.65E3 | | As for Example 2A. |
| – Surface soil, 2b | 2.65E3 | | As for Example 2A. |
| Soil derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Dusty conditions | 5.0E-6 | | As for Example 2A. |
| – Normal conditions | 1.0E-7 | | As for Example 2A. |

TABLE C61. HABITAT DEPENDENT DATA, GRASSLAND

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area adjacent to the lake, $Area_x$ | 2.9E5 | $m^2$ | |
| Area adjacent to the river, $Area_x$ | 3.3E5 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Subsoil, 3a | 1.6E0 | | |
| – Subsoil, 3b | 4.0E-1 | | |
| Wet soil porosity, $\theta$ | | – | |
| – Subsoil, 3a | 4.0E-1 | | Average of 0.3 in the summer and 0.5 in the winter |
| – Surface, 3b | 2.0E-1 | | As for Example 2A |
| Total soil porosity, $\theta_t$ | | – | |
| – Subsoil, 3a | 5.0E-1 | | As for Example 2A |
| – Surface, 3b | 5.0E-1 | | As for Example 2A |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Subsoil, 3a | 2.65E3 | | As for Example 2A |
| – Subsoil, 3b | 2.65E3 | | As for Example 2A |
| Fraction of primary productivity consumed by cattle and transferred to arable area as manure, $M_{32}$ | 4.0E-1 | – | Assuming half of the animal excreta is used to fertilise the arable soil, derived from Knight (1990) |
| Animal occupancy, $O_{an}$ | | h $d^{-1}$ | |
| – Cow | 2.4E1 | | As for Example 2A |
| Soil derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Dusty conditions | 5.0E-6 | | As for Example 2A |
| – Normal conditions | 1.0E-7 | | As for Example 2A |

## TABLE C62. HABITAT DEPENDENT DATA, SHRUBLAND

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area adjacent to the lake, $Area_x$ | 1.9E5 | $m^2$ | |
| Area adjacent to the river, $Area_x$ | 2.0E5 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Surface soil, 4b | 4.0E-1 | | |
| Wet soil porosity, $\theta$ | | – | |
| – Surface soil, 4b | 4.0E-1 | | Average of 0.3 during the summer and 0.5 (saturated) during the winter |
| Total soil porosity, $\theta_t$ | | – | |
| – Surface soil, 4b | 5.0E-1 | | As for Example 2A |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Surface soil, 4b | 2.65E3 | | As for Example 2A |
| Animal occupancy, $O_{an}$ | | h $d^{-1}$ | |
| – Wild animal | 2.4E1 | | Assume wild animal lives in shrubland area |
| – Wild bird | 6.0E0 | | Assume that wild birds spend some time roosting or foraging in shrubland |
| Soil derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Normal conditions | 1.0E-7 | | As for Example 2A |
| Fraction of primary productivity lost to arable land as ash, $B_{42}$ | 1.0E-1 | | Estimated |

## TABLE C63. HABITAT DEPENDENT DATA, WETLAND

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area adjacent to the lake, $Area_x$ | 1.3E5 | $m^2$ | |
| Area adjacent to the river, $Area_x$ | 1.3E5 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Surface soil, 5b | 4.0E-1 | | |
| Wet soil porosity, $\theta$ | | - | |
| – Surface soil, 5b | 5.0E-1 | | Saturated year round |
| Total soil porosity, $\theta_t$ | | - | |
| – Surface soil, 5b | 5.0E-1 | | As for Example 2A |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Surface soil, 5b | 2.65E3 | | As for Example 2A |
| Animal occupancy, $O_{an}$ | | h $d^{-1}$ | |
| – Wild bird | 1.8E1 | | Assume wild birds spend the majority of their time in the wetland |
| Soil derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Normal conditions | 1.0E-7 | | As for Example 2A |

## TABLE C64. HABITAT DEPENDENT DATA, RIVER

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area, $Area_x$ | 2.6E3 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Surface water | 7.5E-1 | | |
| Wet sediment porosity, $\theta$ | | – | |
| – Riverbed sediment | 5.0E-1 | | Assumed saturated |
| Total sediment porosity, $\theta_t$ | | – | |
| – Riverbed sediment | 5.0E-1 | | Assumed same as for soils in Example 2A |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Riverbed sediment | 2.65E3 | | Assumed same as for soils in Example 2A |
| Sediment derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Normal conditions | 1.0E-7 | | May occur at river margins |
| Aerosol/spray level, $AIR_{aero}$ | 1.0E-12 | $m^3$ $m^{-3}$ | Derived from Lawson and Smith (1984) |

## TABLE C65. HABITAT DEPENDENT DATA, LAKE

| Parameter | Value | Units | Justification |
|---|---|---|---|
| Area, $Area_x$ | 2.5E5 | $m^2$ | |
| Thickness, $d_{xx}$ | | m | |
| – Surface water | 3.0E0 | | |
| – Lakebed sediment | 4.0E-1 | | Assumed |
| Wet soil porosity, $\theta$ | | - | |
| – Lakebed sediment | 5.0E-1 | | Assumed saturated |
| Total soil porosity, $\theta_t$ | | - | |
| – Lakebed sediment | 5.0E-1 | | Assumed same as for soil in Example 2A |
| Soil grain density, $\rho$ | | kg $m^{-3}$ | |
| – Lakebed sediment | 2.65E3 | | Assumed same as for soil |
| Sediment resuspension, $r_{lake}$ | 1.9E0 | kg $m^{-2}$ $y^{-1}$ | |
| Gross sedimentation, $h_{lake}$ | 2.6E0 | kg $m^{-2}$ $y^{-1}$ | Derived from the sediment transfer calculations |
| Suspended sediment load, $\alpha_{lake}$ | 6.8E-2 | kg $m^{-3}$ | |
| Soil derived dust level, $dust_s$ | | kg $m^{-3}$ | |
| – Normal conditions | 1.0E-7 | | May occur at lake margins where majority of human activity is likely to occur |
| Aerosol/spray level, $AIR_{aero}$ | 1.0E-12 | $m^3$ $m^{-3}$ | Derived from Lawson and Smith (1984) |

TABLE C66. WATER FLOW RATES, $m^3$ $y^{-1}$

| Area | Transfer | Value, $m^3$ $y^{-1}$ |
|---|---|---|
| Adjacent to the river: | | |
| Area 2 | Groundwater influx, $G_2$ | 1.3E5 |
| | Capillary rise, $U_2$ | 9.5E3 |
| | Recharge, $D_2$ | 1.8E5 |
| | Summer flow from sub-soil, $A_{23}^S$ | 3.5E4 |
| | Winter flow from sub-soil, $A_{23}^W$ | 8.1E5 |
| Area 3 | Groundwater influx, $G_3$ | 1.3E5 |
| | Capillary rise, $U_3$ | 9.3E4 |
| | Flow from sub-soil, $A_{34}$ | 7.4E4 |
| | Flow from surface soil, $I_{36}$ | 9.9E5 |
| Area 4 | Groundwater influx, $G_4$ | 8.0E4 |
| | Spring flow to surface water, $O_4$ | 5.3E4 |
| | Flow from surface soil, $I_{46}$ | 8.5E4 |
| Area 5 | Groundwater influx, $G_5$ | 5.2E4 |
| | Spring flow to surface water, $O_5$ | 5.2E4 |
| Area 6 | Groundwater influx, $G_R$ | 2.6E2 |
| | Discharge to lake, $S_{RL}$ | 6.4E6 |
| Adjacent to the lake: | | |
| Area 2 | Groundwater influx, $G_2$ | 9.9E4 |
| | Capillary rise, $U_2$ | 7.1E3 |
| | Recharge, $D_2$ | 1.3E5 |
| | Summer flow from sub-soil, $A_{23}^S$ | 2.6E4 |
| | Winter flow from sub-soil, $A_{23}^W$ | 3.8E5 |
| Area 3 | Groundwater influx, $G_3$ | 1.2E5 |
| | Capillary rise, $U_3$ | 8.1E4 |
| | Flow from sub-soil, $A_{34}$ | 6.0E4 |
| | Flow from surface soil, $I_{36}$ | 5.4E5 |
| Area 4 | Groundwater influx, $G_4$ | 7.5E4 |
| | Spring flow to surface water, $O_4$ | 5.0E4 |
| | Flow from surface soil, $I_{46}$ | 7.1E4 |
| Area 5 | Groundwater influx, $G_5$ | 5.1E4 |
| | Spring flow to surface water, $O_5$ | 5.1E4 |
| Area 6 | Groundwater influx, $G_L$ | 2.5E4 |
| | Flow from sediment to surface water, $O_L$ | 2.5E4 |
| | Lake discharge, $S_L$ | 7.2E6 |

These data have been derived from separate water flow calculations based on Figures C14 and C15 and the flow equations in Section C4.3.4, combined with data for the habitats, Tables C60–C65. Further details are provided in the BIOMASS Theme 1 Working Material.

TABLE C67. TRANSFER OF MATERIAL BETWEEN HABITAT AREAS

| | | |
|---|---|---|
| Area adjacent to the River: | | |
| Surface soil to the lake, $m^3\ y^{-1}$ | Area 2, $E_{2R}$ | 3.3E-13 |
| | Area 3, $E_{3R}$ | 1.7E-9 |
| | Area 4, $E_{4r}$ | 2.0E-5 |
| | Area 5, $E_{5R}$ | 1.3E0 |
| Fraction of primary productivity lost to the lake as detritus | Area 2, $P_{2R}$ | 1.0E-5 |
| | Area 3, $P_{3R}$ | 2.0E-4 |
| | Area 4, $P_{4R}$ | 2.0E-2 |
| | Area 5, $P_{5R}$ | 2.0E-1 |
| Area adjacent to the lake: | | |
| Surface soil to the lake, $m^3\ y^{-1}$ | Area 2, $E_{2R}$ | 2.5E-13 |
| | Area 3, $E_{3R}$ | 1.4E-9 |
| | Area 4, $E_{4r}$ | 1.9E-5 |
| | Area 5, $E_{5R}$ | 1.3E0 |
| Fraction of primary productivity lost to the lake as detritus | Area 2, $P_{2R}$ | 1.0E-5 |
| | Area 3, $P_{3R}$ | 2.0E-4 |
| | Area 4, $P_{4R}$ | 2.0E-2 |
| | Area 5, $P_{5R}$ | 2.0E-1 |
| Transfer of lake sediment during flooding, $kg\ m^{-2}\ y^{-1}$ | Area 5, $F_{L5}$ | 9.0E-2 |
| | Area 4, $F_{L4}$ | 2.0E-2 |
| Transfer of lake sediment due to dredging, $kg\ m^{-2}\ y^{-1}$ | Area 2, $F_{L2}$ | 1.0E-1 |

The derivation of these data is available in the BIOMASS Theme 1 Working Material.

The cattle of the Livestock Farmer exposure group are assumed to have access to river water during the summer. The location of the Livestock Farming group is therefore adjacent to the river. In the mathematical representation of the pasture land there is no distinction between the pasture soils but, conceptually, it is reasonable to assume access to surface water along the river where pasture reaches down to the river bank.

Cattle therefore obtain all their food intake from pasture land and obtain water from the river during the summer (6 months). During the winter, when the animals are stabled and consume stored foodstuffs, water is supplied from the piped water system which provides uncontaminated water. Meat production requires the largest area of land and it may be assumed that dairy products are obtained from a subset of cattle in the modelled region.

As the exposure groups in ERB2B are broadly composed of a number of individuals, the source of meat and dairy products is likely to be a generic pool of produce. Median consumption rates for fodder and water are appropriate. Overall cattle water intake is, however, set to only half of the value used in ERB2A, to account for six months access to the river. Table C68 indicates how utilisation of agricultural land is apportioned, and summarises data relevant to livestock.

All arable production is obtained from Habitat 2 and the mathematical representation of this area does not distinguish between soils devoted to different crop types. The area of land given over to each crop type may be assumed to be in proportion to consumption in the median diet. The production potential in the area is sufficient for tens of thousands of median consumers.

TABLE C68. CHARACTERISATION OF AGRICULTURAL LAND UTILISATION FACTORS FOR THE ERB2B EXPOSURE GROUPS

| Parameter | Value | Units | Comments |
|---|---|---|---|
| Pasture land (Habitat 3) meat and dairy production | 100% | – | Utilisation factor, including stabling during winter |
| Arable land (Habitat 2) arable production | 90% | – | Some area (10%) assumed for village |
| Arable land (Habitat 2) village area | 10% | – | Arbitrary small amount (does not influence mathematical modelling) |
| Pasture consumption | 70 | kg $d^{-1}$ | Fresh weight, All fodder from Pasture Land (IAEA, 1994) |
| Water consumption | 0.07 | $m^3$ $d^{-1}$ | Total water production (IAEA, 1994) |
| Soil intake with fodder | 0.6 | kg $d^{-1}$ | Dry weight (IAEA, 1994) |

The partitioning between the habitat areas according to activity is summarised in Table C69. Domestic and sleeping activities are assumed to be carried out in locations unique to each of the groups. Villagers are at home in the village, the Farmers have their homes on the land of the habitat corresponding to their farming practice. The Gamekeeper group resides on the shrubland and the Fish Farmer resides on a houseboat on the lake. It is assumed that no residential use is made of the wetland area. Infants reside in the village where and are assumed to sleep and perform domestic activities there. They are no assumed to perform occupational activities;  neither is recreational time outside the domestic environment assumed.

Occupational use is divided according to the type of activity. Arable Farmers spend all their occupational time on the arable land (which includes the village area) and Livestock Farmers spend all their occupational time on the pasture land. It is likely that the village would act as the centre for trade and commerce but the relatively small amount of time spent in the village is not included here.

### C4.6.1. Explanation of exposure group data

The data for exposure groups given in Tables C58 and C59 are explained further here. The overall intent is to be able to rely on the identification of plausible behaviour and  to assign reasonable upper limits to utilisation factors.

The Fish Farmer group is conservatively assumed to spend all occupational time in the vicinity of the lake and river. In contrast the Gamekeeper group is assumed to range over two habitat areas – the shrubland and the wetland. With no additional *a priori* reason to define the partitioning of time between these two locations, occupational utilisation factors are divided according to the ratio of areas – 60% in the shrubland and 40% in the wetland.

The Infant group is assumed to spend all time in the home environment and so recreational use is not identified for this group. For the adult groups making use of lake, wetland and shrubland for a variety of activities (e.g. walking, fishing, hunting, gathering, bird watching etc.) the use of each of these areas must account for all recreational time. This can be done by employing the same broad time balance as was used in ERB2A. Values are given for the annually average number of hours per day spent in the four activity classes in Table C70.

TABLE C69. UTILISATION FACTORS IN THE ERB2B HABITATS FOR THE SEVEN EXPOSURE GROUPS ENGAGED IN DOMESTIC, SLEEPING, OCCUPATIONAL AND RECREATIONAL ACTIVITIES

| Habitat area | Utilisation | Comments |
|---|---|---|
| Domestic and Sleeping: | | |
| – Arable land | 100% | EG1 (Arable Farmer), EG3 (Horticultural Producer), EG6 (Villager), EG7 (Child) |
| – Pasture land | 100% | EG2 (Livestock Farmer) |
| – Shrubland | 100% | EG4 (Gamekeeper) |
| – Wetland | 0% | no groups |
| – Lake | 100% | EG5 (Fish Farmer) |
| Occupational: | | |
| – Arable land | 100% | EG1 (Arable Farmer), EG3 (Horticultural Producer), EG6 (Villager) |
| – Pasture land | 100% | EG2 (Livestock Farmer) |
| – Shrubland | 60% | EG4 Gamekeeper |
| – Wetland | 40% | EG4 Gamekeeper |
| – Lake | 100% | EG5 Fish Farmer |
| Recreationl: | | |
| – Arable land | 0 | Farmland not used for recreational purposes |
| – Pasture land | 0% | Farmland not used for recreational purposes |
| – Shrubland | 53.2% | All groups except EG7 Child |
| – Wetland | 35.3% | All groups except EG7 Child |
| – Lake | 11.5% | All groups except EG7 Child |

TABLE C70. ANNUALLY AVERAGED TIME ENGAGED IN ACTIVITY CLASSES FOR THE ERB2B EXPOSURE GROUPS

| Activity class | Hours per day | |
|---|---|---|
| | EG1 – EG6 (all adult groups) | EG7 (children) |
| Occupational | 8 | 0 |
| Recreational | 4 | 0 |
| Domestic | 4 | 12 |
| Sleeping | 8 | 12 |
| Total | 24 | 24 |

Whereas the Infant group spends 12 hours per day (on average) sleeping and twelve active hours in domestic activities, the adult groups spend eight hours per day working and the same amount sleeping. Recreational and domestic activities account equally for the remaining eight hours.

In order to account for recreational use of the lake it is assumed that an amount of time equivalent to fourteen days is spent vacationing by the lake (implicitly during the summer) and that for this period twelve hours per day are spent boating, swimming and similar activities on the lake and river. Domestic activities are assumed to take place *at home* in the normal surrounding of the group in question.This is a broad ranging assumption. It does not mean that there is a fourteen day vacation, only that time equivalent to fourteen days is spent by the lake. This could be at various times during the year but it is included so as to ensure interaction with the lake/river is represented in the model for exposure group behaviour.

The time spent in this activity corresponds to around 11.5% of all recreational time for the adult groups. The remainder is spent partitioned between shrubland and wetland according to area engaged in the other recreational activities identified above – 53% in the shrubland and 35% in the wetland.

Camping and houseboat activities are identified in Table C65. The former would take place most likely on the shrubland (as the wetland is not suitable). Residential occupancy of this area is assigned to the Gamekeeper group and so this aspect of behaviour is well represented in the exposure group definition. Similarly houseboat residency is part of the Fish Farmer group definition. It may become necessary to define camping and houseboat occupancies for the recreational group in the event that subsequent numerical results indicate that this pathway is relevant to the assessment.

### C4.6.2. Occupancy factors

With the definition of utilisation factors for the seven exposure groups it is possible to complete the numerical characterisation of the exposure groups by converting the utilisation of the six habitats into occupancy factors. These values include not only the amount of time spent in the locations, but also assign the amount of time engaged in different activities on the same land area, distinguishing, for example, between general farmwork and normal atmospheric dust concentrations and activities at high airborne dust loadings. Additional assumptions are required and it's best to approach these on a group by group basis, combining the information in Tables C68 and C69 with that in Table C70.

Most exposures in the ERB2B system will take place at normal airborne dust levels and at normal breathing rates. For assessment purposes it is necessary to consider situations where hard work is undertaken and for which the airborne concentration is high. As a simplifying assumption, the two conditions are combined. Conceptually this means that assessment is for those circumstances where all high-exertion activity happens to occur under dusty conditions. Similarly, those aspects of domestic behaviour at high dust concentrations are also superseded by these assumptions and the Villager group can maintain its role as a reference group in the assessment. As applied to the exposure groups identified here, this condition may most reasonably be applied to agricultural workers, say during ploughing or harvest, or during time spent with livestock during the dry periods of the year. Other occupations could also encounter high dust loadings but, by assigning these factors to exposure groups 1, 2 and 3, the pathway is adequately represented. In practice this means that there is some modification of the utilisation factors shown in Table C72 to account for occupational activities under normal conditions and those undertaken at dusty and high inhalation rates.

The overall occupancy factors for each of the groups by activity and habitat are shown in Table C71. With the exception of the occupational activities, the utilisation factors are those discussed above and the occupancy factors (i.e. the fractional occupancy rates of each habitat area expressed as years per year) are obtained by multiplying the utilisation factor by the fraction of time spent engaged in each activity. Thus, the domestic occupancy factor for the Villager group in the arable land habitat is $1.0 \times 8/24 = 0.333$ (combining Tables C69 and C70) where as for the Child group the factor is $1.0 \times 12/24 = 0.5$.

The partitioning of occupational activity is applied to the agricultural groups, arable, horticultural and livestock producers. High exertion, high dust activities are assumed to be ploughing, harvesting, working with animals under dry conditions. The utilisation factors are derived as follows:

- Arable Farmers (EG1), Horticultural Producers (EG3) – These activities are assumed to occupy the equivalent of eight weeks occupational time (8 hours per day) each year. This amounts to $8 \times 7 \times 4 \times 2 = 448$ hours per year, giving an utilisation factor of 15%.

— Livestock Farmers (EG2) – During the summer (six months per year) it is assumed that the group spends two hours per day working in direct contact with the livestock. This amounts to 336 hours per year, a utilisation factor of 11%.

  The utilisation factors for *normal* conditions are modified to account for this.

The occupancy factors are derived from the utilisation factors and the time balance shown in Table C73. The results are summarised for the set of exposure groups, arranged according to habitat area in Table C74.

TABLE C71. OCCUPANCY FACTORS FOR ALL EXPOSURE GROUPS, BY ACTIVITY AND HABITAT

| Activity Class | Habitat | Utilisation factor | Occupancy factor | Exposure Group |
|---|---|---|---|---|
| Sleeping | Arable Land | 100% | 0.333 | EG1 (Arable Farmer) |
| | | 100% | 0.333 | EG3 (Horticultural Producer) |
| | | 100% | 0.333 | EG6 (Villager) |
| | | 100% | 0.500 | EG7 (Child) |
| | Pasture Land | 100% | 0.333 | EG2 (Livestock Farmer) |
| | Shrubland | 100% | 0.333 | EG4 (Gamekeeper) |
| | Wetland | 0% | 0.000 | no groups |
| | Lake and River | 100% | 0.333 | EG5 (Fish Farmer) |
| Domestic | Arable Land | 100% | 0.167 | EG1 (Arable Farmer) |
| | | 100% | 0.167 | EG3 (Horticultural Producer) |
| | | 100% | 0.167 | EG6 (Villager) |
| | | 100% | 0.500 | EG7 (Child) |
| | Pasture Land | 100% | 0.167 | EG2 (Livestock Farmer) |
| | Shrubland | 100% | 0.167 | EG4 (Gamekeeper) |
| | Wetland | 0% | 0.000 | no groups |
| | Lake and River | 100% | 0.167 | EG5 (Fish Farmer) |
| Recreational | Shrubland | 53.2% | 0.089 | EG1 - EG6 (all adult groups) |
| | Wetland | 35.3% | 0.059 | EG1 - EG6 (all adult groups) |
| | Lake and River | 11.5% | 0.019 | EG1 - EG6 (all adult groups) |
| Occupational #1 (normal dust load, normal breathing rate) | Arable Land | 85% | 0.282 | EG1 (Arable Farmer) |
| | | 85% | 0.282 | EG3 (Horticultural Producer) |
| | | 100% | 0.333 | EG6 (Villager) |
| | Pasture Land | 89% | 0.295 | EG2 (Livestock Farmer) |
| | Shrubland | 60% | 0.200 | EG4 Gamekeeper |
| | Wetland | 40% | 0.133 | EG4 Gamekeeper |
| | Lake and River | 100% | 0.333 | EG5 Fish Farmer |
| Occupational #2 (high dust loading, high breathing rate) | Arable Land | 15% | 0.051 | EG1 (Arable Farmer) |
| | | 15% | 0.051 | EG3 (Horticultural Producer) |
| | | 0% | 0.000 | EG6 (Villager) |
| | Pasture Land | 11% | 0.038 | EG2 (Livestock Farmer) |

TABLE C72. SUMMARY OF OCCUPANCY FACTORS BY EXPOSURE GROUP AND HABITAT

| Activity | Habitat | Exposure group | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | EG1 | EG2 | EG3 | EG4 | EG5 | EG6 | EG7 |
| | | Arable Farmer | Livestock Farmer | Hort. Producer | Game-keeper | Fish Farmer | Villager | Child |
| Sleeping | Arable land | 3.33E-01 | | 3.33E-01 | | | 3.33E-01 | 5.00E-01 |
| | Pasture land | | 3.33E-01 | | | | | |
| | Shrubland | | | | 3.33E-01 | | | |
| | Wetland | | | | | | | |
| | Lake/river | | | | | 3.33E-01 | | |
| Domestic | Arable land | 1.67E-01 | | 1.67E-01 | | | 1.67E-01 | 5.00E-01 |
| | Pasture land | | 1.67E-01 | | | | | |
| | Shrubland | | | | 1.67E-01 | | | |
| | Wetland | | | | | | | |
| | Lake/river | | | | | 1.67E-01 | | |
| Recreational | Arable land | | | | | | | |
| | Pasture land | | | | | | | |
| | Shrubland | 8.86E-02 | 8.86E-02 | 8.86E-02 | 8.86E-02 | 8.86E-02 | 8.86E-02 | |
| | Wetland | 5.89E-02 | 5.89E-02 | 5.89E-02 | 5.89E-02 | 5.89E-02 | 5.89E-02 | |
| | Lake/river | 1.92E-02 | 1.92E-02 | 1.92E-02 | 1.92E-02 | 1.92E-02 | 1.92E-02 | |
| Occupational #1 (normal dust load, normal breathing rate) | Arable land | 2.82E-01 | | 2.82E-01 | | | 3.33E-01 | |
| | Pasture land | | 2.95E-01 | | | | | |
| | Shrubland | | | | 2.00E-01 | | | |
| | Wetland | | | | 1.33E-01 | | | |
| | Lake/river | | | | | 3.33E-01 | | |
| Occupational #2 (high dust loading, high breathing rate) | Arable land | 5.11E-02 | | 5.11E-02 | | | | |
| | Pasture land | | 3.83E-02 | | | | | |
| | Shrubland | | | | | | | |
| | Wetland | | | | | | | |
| | Lake/river | | | | | | | |
| Total | | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

*C4.6.2.1. Transfer of radionuclides in plant detritus and by erosion*

Table C73 shows a comparison of the transfer rates due to detritus movement and erosion. It shows that given the current mathematical representation of these processes, the transfer of radionuclides due to the movement of detritus to the local watercourse is significantly greater (by more than 3 orders of magnitude) from the arable, grassland and shrubland habitats. The transfers are approximately equal for I-129, Np-237 and Nb-94 from the wetland areas. Due to the greater significance of detritus transfer, it was decided that the erosion transfer from the arable, grassland and shrubland habitats could be ignored and that both the detritus and erosion transfers should be included from the wetland habitat. The results in Section C4.9 have been calculated on this basis. However, the original calculational basis and results are retained in the BIOMASS Theme 1 Working Material as an example of how preliminary/side calculations can be used to simplify the model and reduce the burden on data requirements, hence simplifying the application of the data protocol.

TABLE C73. RATIO OF THE DETRITUS TRANSFER RATE TO THE EROSION TRANSFER RATE

| From | Detritus Transfer Rate:Erosion Transfer Rate | | | |
|---|---|---|---|---|
| | I-129 | Np-237 | Tc-99 | Nb-94 |
| Arable land | 1.4E+08 | 2.4E+08 | 4.5E+11 | 2.7E+07 |
| Grassland | 7.8E+05 | 1.1E+06 | 1.6E+09 | 3.7E+05 |
| Shrubland | 1.0E+04 | 2.1E+04 | 2.4E+07 | 2.1E+03 |
| Wetland | 9.5E-01 | 2.0E+00 | 1.4E+03 | 2.0E-01 |

## C4.7. RESULTS FOR ERB2B

Tables C74–C77 present the adult doses for each exposure pathway, assuming the maximum occupancy and consumption rates, based on results from CIEMAT, Jozef Stefan Institute and QuantiSci. Note that the in-growth of Np-237 progeny has been ignored here.

Tables C78–C81 present the results for each radionuclide for the exposure groups considered in ERB2B.

Results are also provided assuming the aquifer is contaminated only under each habitat area. This allows the significance of each habitat to be considered. Firstly, the relative source term to each habitat should be taken into account. Since the aquifer is uniformly contaminated, the groundwater flow into each habitat is proportional to its source term ($M^3$ $y^{-1}$). However doses will also be dependent on the amount of contaminated water reaching unit area of habitat, $my^{-1}$ (see Table C82). Noting then the different source terms to each habitat, Table C83 gives the contributions to results for each radionuclide arising for the release across the geosphere-biosphere interface for each habitat. The totals for all habitats are the same as for Tables C78–C81, which show the separate pathway contributions.

It is clear that the contributions to the arable farmer dose, for example, from the non-arable land exposure pathways can be significant. This is partly because the source term down-slope is larger, so transfer up-slope (though small in mass terms) can be relatively significant. But it is also the case, and probably more significant, that the larger direct discharge to the surface soil in the down-slope habitats results in higher concentrations. Even relatively small consumption of foods taken from the shrubland can give rise, therefore, to significant dose contributions. Note however that data for the wild foods are relatively sparse and the uptake factors assumed are relatively high.

The absolute significance of the results will depend on the nature of the geosphere-biosphere interface and the relative concentrations of source radionuclides in the aquifer. General conclusions on the results in comparision with ERB1 and ERB2, and as a part of a set of ERBs, is given in the Overview, Part A.

TABLE C74. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, I-129 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Consumption of crops: | | | | | |
| – Green vegetables | 1.18E-13 | 148.5 | kg consumed | 1.8E-11 | 420y |
| – Root vegetables | 1.18E-13 | 316.5 | kg consumed | 3.7E-11 | 420y |
| – Grain | 1.18E-13 | 471 | kg consumed | 5.6E-11 | 420y |
| – Wild fungi | 1.07E-11 | 18 | kg consumed | 1.9E-10 | 98y |
| – Wild fruit | 1.25E-10 | 135 | kg consumed | 1.7E-08 | 98y |
| – Wild nuts | 1.25E-10 | 10 | kg consumed | 1.3E-09 | 98y |
| – Other native wild flora and products | 7.63E-11 | 10 | kg consumed | 7.6E-10 | 91y |
| Consumption of animal products: | | | | | |
| – Cattle meat | 3.19E-12 | 207.9 | kg consumed | 6.6E-10 | 98y |
| – Cattle offal | 3.19E-12 | 13.5 | kg consumed | 4.3E-11 | 98y |
| – Cows milk | 3.19E-12 | 744 | kg consumed | 2.4E-09 | 98y |
| – Wild animal meat | 4.85E-11 | 25 | kg consumed | 1.2E-09 | 98y |
| – Wild bird meat | 1.81E-11 | 25 | kg consumed | 4.5E-10 | 91y |
| Consumption of fish from lake | 3.42E-10 | 6.9 | kg consumed | 2.4E-09 | 105y |
| Consumption of soil (not on crops): | | | | | |
| – from arable land | 3.39E-11 | 0.0055 | kg consumed | 1.9E-13 | 420y |
| – from grassland | 2.48E-10 | 0.0055 | kg consumed | 1.4E-12 | 85y |
| – from shrubland | 2.40E-09 | 0.0021 | kg consumed | 5.0E-12 | 98y |
| – from wetland | 2.21E-09 | 0.0014 | kg consumed | 3.1E-12 | 91y |
| – from river | 1.49E-09 | 0.0002 | kg consumed | 3.0E-13 | 85y |
| – from lake | 5.12E-09 | 0.0002 | kg consumed | 1.0E-12 | 482y |
| External irradiation from soil/sediment: | | | | | |
| – from arable land | 1.18E-16 | 2920 | h | 3.4E-13 | 420y |
| – from grassland | 8.60E-16 | 2922 | h | 2.5E-12 | 85y |
| – from shrubland | 9.41E-15 | 2530 | h | 2.4E-11 | 98y |
| – from wetland | 9.18E-15 | 1682 | h | 1.5E-11 | 91y |
| – from river | 6.17E-15 | 81 | h | 5.0E-13 | 85y |
| – from lake | 2.12E-14 | 3007 | h | 6.4E-11 | 482y |
| External irradiation, immersion in water: | | | | | |
| – from lake | 3.39E-16 | 100 | h | 3.4E-14 | 105y |

TABLE C74. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, I-129 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS (CONTINUED)

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Inhalation of dust from soil | | | | | |
| Normal activity: | | | | | |
| – from arable land | 1.51E-18 | 2919 | h | 4.4E-15 | 420y |
| – from grassland | 1.10E-17 | 2586 | h | 2.8E-14 | 85y |
| – from shrubland | 1.21E-16 | 2530 | h | 3.1E-13 | 98y |
| – from wetland | 1.18E-16 | 1682 | h | 2.0E-13 | 91y |
| – from river | 8.04E-17 | 81 | h | 6.5E-15 | 85y |
| – from lake | 2.77E-16 | 3007 | h | 8.3E-13 | 482y |
| Hard physical activity: | | | | | |
| – from arable land | 1.26E-16 | 448 | h | 5.6E-14 | 420y |
| – from grassland | 9.20E-16 | 336 | h | 3.1E-13 | 85y |
| Inhalation of aerosols/spray: | | | | | |
| – from river | 2.68E-21 | 81 | h | 2.2E-19 | 85y |
| – from lake | 4.57E-21 | 3007 | h | 1.4E-17 | 105y |

TABLE C75. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Np-237 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Consumption of crops: | | | | | |
| – Ggreen vegetables | 1.07E-12 | 148.5 | kg consumed | 1.6E-10 | 1800y |
| – Root vegetables | 1.07E-12 | 316.5 | kg consumed | 3.4E-10 | 1800y |
| – Grain | 4.30E-13 | 471 | kg consumed | 2.0E-10 | 1800y |
| – Wild fungi | 7.63E-09 | 18 | kg consumed | 1.4E-07 | 2220y |
| – Wild fruit | 4.01E-11 | 135 | kg consumed | 5.4E-09 | 2220y |
| – Wild nuts | 3.74E-11 | 10 | kg consumed | 3.7E-10 | 2220y |
| – Other native wild flora and products | 6.37E-09 | 10 | kg consumed | 6.4E-08 | 3370y |
| Consumption of animal products: | | | | | |
| – Cattle meat | 1.70E-13 | 207.9 | kg consumed | 3.5E-11 | 1040y |
| – Cattle offal | 1.70E-13 | 13.5 | kg consumed | 2.3E-12 | 1040y |
| – Cows milk | 1.70E-13 | 744 | kg consumed | 1.3E-10 | 1040y |
| – Wild animal meat | 9.14E-12 | 25 | kg consumed | 2.3E-10 | 2220y |
| – Wild bird meat | 7.71E-12 | 25 | kg consumed | 1.9E-10 | 3370y |
| Consumption of fish from lake | 1.13E-10 | 6.9 | kg consumed | 7.8E-10 | 1800y |
| Consumption of soil (not on crops): | | | | | |
| – from arable land | 1.85E-10 | 0.0055 | kg consumed | 1.0E-12 | 1800y |
| – from grassland | 7.54E-10 | 0.0055 | kg consumed | 4.1E-12 | 277y |
| – from shrubland | 1.03E-07 | 0.0021 | kg consumed | 2.2E-10 | 2380y |
| – from wetland | 8.72E-08 | 0.0014 | kg consumed | 1.2E-10 | 3370y |
| – from river | 2.49E-09 | 0.0002 | kg consumed | 5.0E-13 | 1680y |
| – from lake | 6.92E-09 | 0.0002 | kg consumed | 1.4E-12 | 1460y |
| External irradiation from soil/sediment: | | | | | |
| – from arable land | 3.84E-15 | 2920 | h | 1.1E-11 | 1800y |
| – from grassland | 1.57E-14 | 2922 | h | 4.6E-11 | 277y |
| – from shrubland | 2.42E-12 | 2530 | h | 6.1E-09 | 2220y |
| – from wetland | 2.17E-12 | 1682 | h | 3.6E-09 | 3370y |
| – from river | 6.21E-14 | 81 | h | 5.0E-12 | 1800y |
| – from lake | 1.72E-13 | 3007 | h | 5.2E-10 | 1370y |
| External irradiation, immersion in water: | | | | | |
| – from lake | 8.89E-16 | 100 | h | 8.9E-14 | 1800y |

TABLE C75. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Np-237 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS (CONTINUED)

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Inhalation of dust from soil | | | | | |
| Normal activity: | | | | | |
| – from arable land | 1.15E-14 | 2919 | h | 3.4E-11 | 1680y |
| – from grassland | 4.71E-14 | 2586 | h | 1.2E-10 | 277y |
| – from shrubland | 7.29E-12 | 2530 | h | 1.8E-08 | 2220y |
| – from wetland | 6.55E-12 | 1682 | h | 1.1E-08 | 3370y |
| – from river | 1.87E-13 | 81 | h | 1.5E-11 | 1680y |
| – from lake | 5.20E-13 | 3007 | h | 1.6E-09 | 1460y |
| Hard physical activity: | | | | | |
| – from arable land | 9.62E-13 | 448 | h | 4.3E-10 | 1800y |
| – from grassland | 3.92E-12 | 336 | h | 1.3E-09 | 277y |
| Inhalation of aerosols/spray | | | | | |
| – from river | 3.75E-18 | 81 | h | 3.0E-16 | 1800y |
| – from lake | 6.35E-18 | 3007 | h | 1.9E-14 | 1800y |

TABLE C76. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Tc-99 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Consumption of crops: | | | | | |
| – Green vegetables | 3.88E-14 | 148.5 | kg consumed | 5.8E-12 | 7y |
| – Root vegetables | 3.88E-14 | 316.5 | kg consumed | 1.2E-11 | 7y |
| – Grain | 3.88E-14 | 471 | kg consumed | 1.8E-11 | 7y |
| – Wild fungi | 9.05E-10 | 18 | kg consumed | 1.6E-08 | 5y |
| – Wild fruit | 2.09E-11 | 135 | kg consumed | 2.8E-09 | 5y |
| – Wild nuts | 2.09E-11 | 10 | kg consumed | 2.1E-10 | 5y |
| – Other native wild flora and products | 3.99E-11 | 10 | kg consumed | 4.0E-10 | 6y |
| Consumption of animal products: | | | | | |
| – Cattle meat | 1.44E-13 | 207.9 | kg consumed | 3.0E-11 | 3y |
| – Cattle offal | 5.04E-14 | 13.5 | kg consumed | 6.8E-13 | 3y |
| – Cows milk | 1.80E-13 | 744 | kg consumed | 1.3E-10 | 3y |
| – Wild animal meat | 2.52E-11 | 25 | kg consumed | 6.3E-10 | 5y |
| – Wild bird meat | 1.44E-11 | 25 | kg consumed | 3.6E-10 | 6y |
| Consumption of fish from lake | 1.02E-12 | 6.9 | kg consumed | 7.0E-12 | 5y |
| Consumption of soil (not on crops): | | | | | |
| – from arable land | 3.38E-15 | 0.0055 | kg consumed | 1.9E-17 | 7y |
| – from grassland | 2.39E-14 | 0.0055 | kg consumed | 1.3E-16 | 3y |
| – from shrubland | 8.91E-13 | 0.0021 | kg consumed | 1.9E-15 | 5y |
| – from wetland | 8.05E-13 | 0.0014 | kg consumed | 1.1E-15 | 6y |
| – from river | 2.86E-13 | 0.0002 | kg consumed | 5.7E-17 | 4y |
| – from lake | 3.94E-12 | 0.0002 | kg consumed | 7.9E-16 | 5y |
| External irradiation from soil/sediment: | | | | | |
| – from arable land | 1.93E-20 | 2920 | h | 5.6E-17 | 7y |
| – from grassland | 1.36E-19 | 2922 | h | 4.0E-16 | 3y |
| – from shrubland | 5.76E-18 | 2530 | h | 1.5E-14 | 5y |
| – from wetland | 5.51E-18 | 1682 | h | 9.3E-15 | 6y |
| – from river | 1.95E-18 | 81 | h | 1.6E-16 | 4y |
| – from lake | 2.69E-17 | 3007 | h | 8.1E-14 | 105y |
| External irradiation, immersion in water: | | | | | |
| – from lake | 1.16E-18 | 100 | h | 1.2E-16 | 5y |

TABLE C76. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Tc-99 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS (CONTINUED)

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Inhalation of dust from soil | | | | | |
| Normal activity: | | | | | |
| – from arable land | 9.59E-22 | 2919 | h | 2.8E-18 | 7y |
| – from grassland | 6.78E-21 | 2586 | h | 1.8E-17 | 3y |
| – from shrubland | 2.35E-18 | 2530 | h | 5.9E-15 | 5y |
| – from wetland | 2.16E-18 | 1682 | h | 3.6E-15 | 7y |
| – from river | 9.24E-19 | 81 | h | 7.5E-17 | 4y |
| – from lake | 1.27E-17 | 3007 | h | 3.8E-14 | 98y |
| Hard physical activity: | | | | | |
| – from arable land | 7.99E-20 | 448 | h | 3.6E-17 | 7y |
| – from grassland | 5.65E-19 | 336 | h | 1.9E-16 | 3y |
| Inhalation of aerosols/spray | | | | | |
| – from river | 9.59E-22 | 81 | h | 7.8E-20 | 4y |
| – from lake | 1.65E-21 | 3007 | h | 5.0E-18 | 5y |

TABLE C77. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Nb-94 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Consumption of crops: | | | | | |
| – Green vegetables | 1.52E-13 | 148.5 | kg consumed | 2.3E-11 | 9550y |
| – Root vegetables | 9.12E-13 | 316.5 | kg consumed | 2.9E-10 | 9550y |
| – Grain | 5.86E-13 | 471 | kg consumed | 2.8E-10 | 9550y |
| – Wild fungi | 1.63E-11 | 18 | kg consumed | 2.9E-10 | 7230y |
| – Wild fruit | 8.18E-12 | 135 | kg consumed | 1.1E-09 | 7230y |
| – Wild nuts | 8.11E-12 | 10 | kg consumed | 8.1E-11 | 7230y |
| – Other native wild flora and products | 1.66E-11 | 10 | kg consumed | 1.7E-10 | 6290y |
| Consumption of animal products: | | | | | |
| – Cattle meat | 5.03E-14 | 207.9 | kg consumed | 1.0E-11 | 8310y |
| – Cattle offal | 6.21E-13 | 13.5 | kg consumed | 8.4E-12 | 8310y |
| – Cows milk | 1.18E-16 | 744 | kg consumed | 8.8E-14 | 8310y |
| – Wild animal meat | 7.88E-13 | 25 | kg consumed | 2.0E-11 | 7230y |
| – Wild bird meat | 1.70E-12 | 25 | kg consumed | 4.3E-11 | 6290y |
| Consumption of fish from lake | 2.87E-11 | 6.9 | kg consumed | 2.0E-10 | 7230y |
| Consumption of soil (not on crops): | | | | | |
| – from arable land | 3.14E-10 | 0.0055 | kg consumed | 1.7E-12 | 9550y |
| – from grassland | 3.59E-10 | 0.0055 | kg consumed | 2.0E-12 | 8310y |
| – from shrubland | 2.49E-09 | 0.0021 | kg consumed | 5.2E-12 | 7230y |
| – from wetland | 2.41E-09 | 0.0014 | kg consumed | 3.4E-12 | 6290y |
| – from river | 7.80E-10 | 0.0002 | kg consumed | 1.6E-13 | 7230y |
| – from lake | 7.67E-10 | 0.0002 | kg consumed | 1.5E-13 | 7230y |
| External irradiation from soil/sediment: | | | | | |
| – from arable land | 5.36E-11 | 2920 | h | 1.6E-07 | 9550y |
| – from grassland | 6.11E-11 | 2922 | h | 1.8E-07 | 8310y |
| – from shrubland | 4.80E-10 | 2530 | h | 1.2E-06 | 7230y |
| – from wetland | 4.91E-10 | 1682 | h | 8.3E-07 | 6290y |
| – from river | 1.59E-10 | 81 | h | 1.3E-08 | 6750y |
| – from lake | 1.57E-10 | 3007 | h | 4.7E-07 | 7230y |
| External irradiation, immersion in water: | | | | | |
| – from lake | 5.68E-14 | 100 | h | 5.7E-12 | 7230y |

TABLE C77. BIOMASS THEME 1, EXAMPLE REFERENCE BIOSPHERE 2B, Nb-94 UNIT EXPOSURE AND A PRIORI ADULT DOSES FOR CRITICAL EXPOSURES VIA INDIVIDUAL EXPOSURE PATHWAYS (CONTINUED)

| Dose name | Dose, Sv/y per unit exposure | Exposure | Units of exposure | Equilibrium dose, Sv/y *a priori* consumption or occupancy | Time after release commences to 90% of maximum dose |
|---|---|---|---|---|---|
| Inhalation of dust from soil | | | | | |
| Normal activity: | | | | | |
| – from arable land | 2.53E-15 | 2919 | h | 7.4E-12 | 9550y |
| – from grassland | 2.88E-15 | 2586 | h | 7.4E-12 | 7750y |
| – from shrubland | 2.27E-14 | 2530 | h | 5.7E-11 | 7230y |
| – from wetland | 2.32E-14 | 1682 | h | 3.9E-11 | 6290y |
| – from river | 7.51E-15 | 81 | h | 6.1E-13 | 7230y |
| – from lake | 7.39E-15 | 3007 | h | 2.2E-11 | 7750y |
| Hard physical activity: | | | | | |
| – from arable land | 2.11E-13 | 448 | h | 9.5E-11 | 9550y |
| – from grassland | 2.40E-13 | 336 | h | 8.1E-11 | 7750y |
| Inhalation of aerosols/spray (51): | | | | | |
| – from river | 7.51E-21 | 81 | h | 6.1E-19 | 7230y |
| – from lake | 1.12E-20 | 3007 | h | 3.4E-17 | 7230y |

## TABLE C78. EXPOSURE GROUP RESULTS FOR I-129 AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Arable Farmer | | Livestock farmer | | Horticultural producer | | Gamekeeper | | Fisherman | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Crop consumption: | | | | | | | | | | | | | | | |
| – Green vegetables | kg/y | 49.5 | 5.8E-12 | 49.5 | 5.8E-12 | 148.5 | 1.8E-11 | 49.5 | 5.8E-12 | 49.5 | 5.8E-12 | 49.5 | 5.8E-12 | 29 | 5.6E-12 |
| – Root vegetables | kg/y | 316.5 | 3.7E-11 | 105.5 | 1.2E-11 | 316.5 | 3.7E-11 | 105.5 | 1.2E-11 | 105.5 | 1.2E-11 | 105.5 | 1.2E-11 | 51.6 | 1.0E-11 |
| – Grain | kg/y | 471 | 5.6E-11 | 157 | 1.9E-11 | 157 | 1.9E-11 | 157 | 1.9E-11 | 157 | 1.9E-11 | 157 | 1.9E-11 | 14.8 | 2.9E-12 |
| – Wild fungi | kg/y | 6 | 6.4E-11 | 6 | 6.4E-11 | 6 | 6.4E-11 | 18 | 1.9E-10 | 6 | 6.4E-11 | 6 | 6.4E-11 | 3 | 5.3E-11 |
| – Wild fruit | kg/y | 45 | 5.6E-09 | 45 | 5.6E-09 | 45 | 5.6E-09 | 135 | 1.7E-08 | 45 | 5.6E-09 | 45 | 5.6E-09 | 33.6 | 6.9E-09 |
| – Wild nuts | kg/y | 1.5 | 1.9E-10 | 1.5 | 1.9E-10 | 1.5 | 1.9E-10 | 10 | 1.3E-09 | 1.5 | 1.9E-10 | 1.5 | 1.9E-10 | 1 | 2.1E-10 |
| – Other native wild flora and products | kg/y | 1.5 | 1.1E-10 | 1.5 | 1.1E-10 | 1.5 | 1.1E-10 | 10 | 7.6E-10 | 1.5 | 1.1E-10 | 1.5 | 1.1E-10 | 1 | 1.3E-10 |
| Animal product consumption: | | | | | | | | | | | | | | | |
| – Cattle meat | kg/y | 69.3 | 2.2E-10 | 207.9 | 6.6E-10 | 69.3 | 2.2E-10 | 69.3 | 2.2E-10 | 69.3 | 2.2E-10 | 69.3 | 2.2E-10 | 29.5 | 1.5E-10 |
| – Cattle offal | kg/y | 4.5 | 1.4E-11 | 13.5 | 4.3E-11 | 4.5 | 1.4E-11 | 4.5 | 1.4E-11 | 4.5 | 1.4E-11 | 4.5 | 1.4E-11 | 0.6 | 3.1E-12 |
| – Cows milk | kg/y | 248 | 7.9E-10 | 744 | 2.4E-09 | 248 | 7.9E-10 | 248 | 7.9E-10 | 248 | 7.9E-10 | 248 | 7.9E-10 | 159.9 | 8.3E-10 |
| – Wild animal meat | kg/y | 8.75 | 4.2E-10 | 8.75 | 4.2E-10 | 8.75 | 4.2E-10 | 25 | 1.2E-09 | 8.75 | 4.2E-10 | 8.75 | 4.2E-10 | 4.5 | 3.6E-10 |
| – Wild bird meat | kg/y | 8.75 | 1.6E-10 | 8.75 | 1.6E-10 | 8.75 | 1.6E-10 | 25 | 4.5E-10 | 8.75 | 1.6E-10 | 8.75 | 1.6E-10 | 8.75 | 2.6E-10 |
| Fish consumption from lake | kg/y | 2.3 | 7.9E-10 | 2.3 | 7.9E-10 | 2.3 | 7.9E-10 | 2.3 | 7.9E-10 | 6.9 | 2.4E-09 | 2.3 | 7.9E-10 | 0 | 0.0E+00 |
| Soil consumption (not on crops): | | | | | | | | | | | | | | | |
| – from arable land | kg/y | 0.0055 | 1.9E-13 | | 0.0E+00 | 0.0025 | 8.5E-14 | | 0.0E+00 | | 0.0E+00 | 0.0025 | 8.5E-14 | 0.037 | 2.1E-12 |
| – from grassland | kg/y | | 0.0E+00 | 0.0055 | 1.4E-12 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 |
| – from shrubland | kg/y | 0.0015 | 3.6E-12 | 0.0015 | 3.6E-12 | 0.0007 | 1.7E-12 | 0.0021 | 5.0E-12 | 0.0007 | 1.7E-12 | 0.0007 | 1.7E-12 | | 0.0E+00 |
| – from wetland | kg/y | 0.001 | 2.2E-12 | 0.001 | 2.2E-12 | 0.0004 | 8.8E-13 | 0.0014 | 3.1E-12 | 0.0004 | 8.8E-13 | 0.0004 | 8.8E-13 | | 0.0E+00 |
| – from river | kg/y | 0.0002 | 3.0E-13 | 0.0002 | 3.0E-13 | 0.0001 | 1.5E-13 | 0.0001 | 1.5E-13 | 0.0001 | 1.5E-13 | 0.0001 | 1.5E-13 | | 0.0E+00 |
| – from lake | kg/y | 0.0002 | 1.0E-12 | 0.0002 | 1.0E-12 | 0.0001 | 5.1E-13 | 0.0001 | 5.1E-13 | 0.0025 | 1.3E-11 | 0.0001 | 5.1E-13 | | 0.0E+00 |
| External from soil: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2920 | 3.4E-13 | | 0.0E+00 | 2920 | 3.4E-13 | | 0.0E+00 | | 0.0E+00 | 2919 | 3.4E-13 | 4383 | 5.2E-13 |
| – from grassland | h/y | | 0.0E+00 | 2922 | 2.5E-12 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 |
| – from shrubland | h/y | 777 | 7.3E-12 | 777 | 7.3E-12 | 777 | 7.3E-12 | 2530 | 2.4E-11 | 777 | 7.3E-12 | 777 | 7.3E-12 | | 0.0E+00 |
| – from wetland | h/y | 516 | 4.7E-12 | 516 | 4.7E-12 | 516 | 4.7E-12 | 1682 | 1.5E-11 | 516 | 4.7E-12 | 516 | 4.7E-12 | | 0.0E+00 |
| – from river | h/y | 81 | 5.0E-13 | 81 | 5.0E-13 | 81 | 5.0E-13 | 81 | 5.0E-13 | 81 | 5.0E-13 | 81 | 5.0E-13 | | 0.0E+00 |
| – from lake | h/y | 88 | 1.9E-12 | 88 | 1.9E-12 | 88 | 1.9E-12 | 88 | 1.9E-12 | 3007 | 6.4E-11 | 88 | 1.9E-12 | | 0.0E+00 |
| External from immersion in water from lake | h/y | 25 | 8.5E-15 | 25 | 8.5E-15 | 25 | 8.5E-15 | 25 | 8.5E-15 | 100 | 3.4E-14 | 25 | 8.5E-15 | | 0.0E+00 |
| Inhalation of dust | | | | | | | | | | | | | | | |
| During normal activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2472 | 3.7E-15 | | 0.0E+00 | 2472 | 3.7E-15 | | 0.0E+00 | | 0.0E+00 | 2919 | 4.4E-15 | 4383 | 1.3E-14 |
| – from grassland | h/y | | 0.0E+00 | 2586 | 2.8E-14 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 |
| – from shrubland | h/y | 777 | 9.4E-14 | 777 | 9.4E-14 | 777 | 9.4E-14 | 2530 | 3.1E-13 | 777 | 9.4E-14 | 777 | 9.4E-14 | | 0.0E+00 |
| – from wetland | h/y | 516 | 6.1E-14 | 516 | 6.1E-14 | 516 | 6.1E-14 | 1682 | 2.0E-13 | 516 | 6.1E-14 | 516 | 6.1E-14 | | 0.0E+00 |
| – from river | h/y | 81 | 6.5E-15 | 81 | 6.5E-15 | 81 | 6.5E-15 | 81 | 6.5E-15 | 81 | 6.5E-15 | 81 | 6.5E-15 | | 0.0E+00 |
| – from lake | h/y | 88 | 2.4E-14 | 88 | 2.4E-14 | 88 | 2.4E-14 | 88 | 2.4E-14 | 3007 | 8.3E-13 | 88 | 2.4E-14 | | 0.0E+00 |
| During hard physical activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 448 | 5.6E-14 | | 0.0E+00 | 448 | 5.6E-14 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 |
| – from grassland | h/y | | 0.0E+00 | 336 | 3.1E-13 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 | | 0.0E+00 |
| Inhalation of aerosols/spray: | | | | | | | | | | | | | | | |
| – from river | h/y | 81 | 2.2E-19 | 81 | 2.2E-19 | 81 | 2.2E-19 | 81 | 2.2E-19 | 81 | 2.2E-19 | 81 | 2.2E-19 | | 0.0E+00 |
| – from lake | h/y | 88 | 4.0E-19 | 88 | 4.0E-19 | 88 | 4.0E-19 | 88 | 4.0E-19 | 3007 | 1.4E-17 | 88 | 4.0E-19 | | 0.0E+00 |
| Total | | | 8.5E-09 | | 1.1E-08 | | 8.5E-09 | | 2.3E-08 | | 1.0E-08 | | 8.4E-09 | | 8.9E-09 |

# TABLE C79. EXPOSURE GROUP RESULTS FOR Np-237 AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Arable Farmer | | Livestock farmer | | Horticultural producer | | Gamekeeper | | Fisherman | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Crop consumption: | | | | | | | | | | | | | | | |
| – Green vegetables | kg/y | 49.5 | 5.3E-11 | 49.5 | 5.3E-11 | 148.5 | 1.6E-10 | 49.5 | 5.3E-11 | 49.5 | 5.3E-11 | 49.5 | 5.3E-11 | 29 | 5.6E-10 |
| – Root vegetables | kg/y | 316.5 | 3.4E-10 | 105.5 | 1.1E-10 | 316.5 | 3.4E-10 | 105.5 | 1.1E-10 | 105.5 | 1.1E-10 | 105.5 | 1.1E-10 | 51.6 | 1.0E-09 |
| – Grain | kg/y | 471 | 2.0E-10 | 157 | 6.8E-11 | 157 | 6.8E-11 | 157 | 6.8E-11 | 157 | 6.8E-11 | 157 | 6.8E-11 | 14.8 | 1.2E-10 |
| – Wild fungi | kg/y | 6 | 4.6E-08 | 6 | 4.6E-08 | 6 | 4.6E-08 | 18 | 1.4E-07 | 6 | 4.6E-08 | 6 | 4.6E-08 | 3 | 4.2E-07 |
| – Wild fruit | kg/y | 45 | 1.8E-09 | 45 | 1.8E-09 | 45 | 1.8E-09 | 135 | 5.4E-09 | 45 | 1.8E-09 | 45 | 1.8E-09 | 33.6 | 2.4E-08 |
| – Wild nuts | kg/y | 1.5 | 5.6E-11 | 1.5 | 5.6E-11 | 1.5 | 5.6E-11 | 10 | 3.7E-10 | 1.5 | 5.6E-11 | 1.5 | 5.6E-11 | 1 | 6.8E-10 |
| – Other native wild flora and products | kg/y | 1.5 | 9.6E-09 | 1.5 | 9.6E-09 | 1.5 | 9.6E-09 | 10 | 6.4E-08 | 1.5 | 9.6E-09 | 1.5 | 9.6E-09 | 1 | 1.2E-07 |
| Animal product consumption: | | | | | | | | | | | | | | | |
| – Cattle meat | kg/y | 69.3 | 1.2E-11 | 207.9 | 3.5E-11 | 69.3 | 1.2E-11 | 69.3 | 1.2E-11 | 69.3 | 1.2E-11 | 69.3 | 1.2E-11 | 29.5 | 9.1E-11 |
| – Cattle offal | kg/y | 4.5 | 7.7E-13 | 13.5 | 2.3E-12 | 4.5 | 7.7E-13 | 4.5 | 7.7E-13 | 4.5 | 7.7E-13 | 4.5 | 7.7E-13 | 0.6 | 1.8E-12 |
| – Cows milk | kg/y | 248 | 4.2E-11 | 744 | 1.3E-10 | 248 | 4.2E-11 | 248 | 4.2E-11 | 248 | 4.2E-11 | 248 | 4.2E-11 | 159.9 | 4.9E-10 |
| – Wild animal meat | kg/y | 8.75 | 8.0E-11 | 8.75 | 8.0E-11 | 8.75 | 8.0E-11 | 25 | 2.3E-10 | 8.75 | 8.0E-11 | 8.75 | 8.0E-11 | 4.5 | 7.5E-10 |
| – Wild bird meat | kg/y | 8.75 | 6.7E-11 | 8.75 | 6.7E-11 | 8.75 | 6.7E-11 | 25 | 1.9E-10 | 8.75 | 6.7E-11 | 8.75 | 6.7E-11 | 8.75 | 1.2E-09 |
| Fish consumption from lake | kg/y | 2.3 | 2.6E-10 | 2.3 | 2.6E-10 | 2.3 | 2.6E-10 | 2.3 | 2.6E-10 | 6.9 | 7.8E-10 | 2.3 | 2.6E-10 | 0 | 0.0E+00 |
| Soil consumption (not on crops): | | | | | | | | | | | | | | | |
| – from arable land | kg/y | 0.0055 | 1.0E-12 | 0 | 0.0E+00 | 0.0025 | 4.6E-13 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0.0025 | 4.6E-13 | 0.037 | 1.2E-10 |
| – from grassland | kg/y | 0 | 0.0E+00 | 0.0055 | 4.1E-12 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | kg/y | 0.0015 | 1.5E-10 | 0.0015 | 1.5E-10 | 0.0007 | 7.2E-11 | 0.0021 | 2.2E-10 | 0.0007 | 7.2E-11 | 0.0007 | 7.2E-11 | 0 | 0.0E+00 |
| – from wetland | kg/y | 0.001 | 8.7E-11 | 0.001 | 8.7E-11 | 0.0004 | 3.5E-11 | 0.0014 | 1.2E-10 | 0.0004 | 3.5E-11 | 0.0004 | 3.5E-11 | 0 | 0.0E+00 |
| – from river | kg/y | 0.0002 | 5.0E-13 | 0.0002 | 5.0E-13 | 0.0001 | 2.5E-13 | 0.0001 | 2.5E-13 | 0.0001 | 2.5E-13 | 0.0001 | 2.5E-13 | 0 | 0.0E+00 |
| – from lake | kg/y | 0.0002 | 1.4E-12 | 0.0002 | 1.4E-12 | 0.0001 | 6.9E-13 | 0.0001 | 6.9E-13 | 0.0025 | 1.7E-11 | 0.0001 | 6.9E-13 | 0 | 0.0E+00 |
| External from soil: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2920 | 1.1E-11 | 0 | 0.0E+00 | 2920 | 1.1E-11 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 1.1E-11 | 4383 | 1.7E-11 |
| – from grassland | h/y | 0 | 0.0E+00 | 2922 | 4.6E-11 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 1.9E-09 | 777 | 1.9E-09 | 777 | 1.9E-09 | 2530 | 6.1E-09 | 777 | 1.9E-09 | 777 | 1.9E-09 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 1.1E-09 | 516 | 1.1E-09 | 516 | 1.1E-09 | 1682 | 3.6E-09 | 516 | 1.1E-09 | 516 | 1.1E-09 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 5.0E-12 | 81 | 5.0E-12 | 81 | 5.0E-12 | 81 | 5.0E-12 | 81 | 5.0E-12 | 81 | 5.0E-12 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 1.5E-11 | 88 | 1.5E-11 | 88 | 1.5E-11 | 88 | 1.5E-11 | 3007 | 5.2E-10 | 88 | 1.5E-11 | 0 | 0.0E+00 |
| External from immersion in water from lake | h/y | 25 | 2.2E-14 | 25 | 2.2E-14 | 25 | 2.2E-14 | 25 | 2.2E-14 | 100 | 8.9E-14 | 25 | 2.2E-14 | 0 | 0.0E+00 |
| Inhalation of dust: | | | | | | | | | | | | | | | |
| During normal activity | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2472 | 2.8E-11 | 0 | 0.0E+00 | 2472 | 2.8E-11 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 3.4E-11 | 4383 | 9.9E-11 |
| – from grassland | h/y | 0 | 0.0E+00 | 2586 | 1.2E-10 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 5.7E-09 | 777 | 5.7E-09 | 777 | 5.7E-09 | 2530 | 1.8E-08 | 777 | 5.7E-09 | 777 | 5.7E-09 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 3.4E-09 | 516 | 3.4E-09 | 516 | 3.4E-09 | 1682 | 1.1E-08 | 516 | 3.4E-09 | 516 | 3.4E-09 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 1.5E-11 | 81 | 1.5E-11 | 81 | 1.5E-11 | 81 | 1.5E-11 | 81 | 1.5E-11 | 81 | 1.5E-11 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 4.6E-11 | 88 | 4.6E-11 | 88 | 4.6E-11 | 88 | 4.6E-11 | 3007 | 1.6E-09 | 88 | 4.6E-11 | 0 | 0.0E+00 |
| During hard physical activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 448 | 4.3E-10 | 0 | 0.0E+00 | 448 | 4.3E-10 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from grassland | h/y | 0 | 0.0E+00 | 336 | 1.3E-09 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Inhalation of aerosols/spray: | | | | | | | | | | | | | | | |
| – from river | h/y | 81 | 3.0E-16 | 81 | 3.0E-16 | 81 | 3.0E-16 | 81 | 3.0E-16 | 81 | 3.0E-16 | 81 | 3.0E-16 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 5.6E-16 | 88 | 5.6E-16 | 88 | 5.6E-16 | 88 | 5.6E-16 | 3007 | 1.9E-14 | 88 | 5.6E-16 | 0 | 0.0E+00 |
| Total | | | 7.1E-08 | | 7.2E-08 | | 7.1E-08 | | 2.5E-07 | | 7.3E-08 | | 7.0E-08 | | 5.6E-07 |

## TABLE C80. EXPOSURE GROUP RESULTS FOR Tc-99 AT EQUILIBRIUM

| Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Arable Farmer | | Livestock farmer | | Horticultural producer | | Gamekeeper | | Fisherman | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Crop consumption: | | | | | | | | | | | | | | | |
| – Green vegetables | kg/y | 49.5 | 1.9E-12 | 49.5 | 1.9E-12 | 148.5 | 5.8E-12 | 49.5 | 1.9E-12 | 49.5 | 1.9E-12 | 49.5 | 1.9E-12 | 29 | 1.8E-11 |
| – Root vegetables | kg/y | 316.5 | 1.2E-11 | 105.5 | 4.1E-12 | 316.5 | 1.2E-11 | 105.5 | 4.1E-12 | 105.5 | 4.1E-12 | 105.5 | 4.1E-12 | 51.6 | 3.1E-11 |
| – Grain | kg/y | 471 | 1.8E-11 | 157 | 6.1E-12 | 157 | 6.1E-12 | 157 | 6.1E-12 | 157 | 6.1E-12 | 157 | 6.1E-12 | 14.8 | 9.0E-12 |
| – Wild fungi | kg/y | 6 | 5.4E-09 | 6 | 5.4E-09 | 6 | 5.4E-09 | 18 | 1.6E-08 | 6 | 5.4E-09 | 6 | 5.4E-09 | 3 | 4.2E-08 |
| – Wild fruit | kg/y | 45 | 9.4E-10 | 45 | 9.4E-10 | 45 | 9.4E-10 | 135 | 2.8E-09 | 45 | 9.4E-10 | 45 | 9.4E-10 | 33.6 | 1.1E-08 |
| – Wild nuts | kg/y | 1.5 | 3.1E-11 | 1.5 | 3.1E-11 | 1.5 | 3.1E-11 | 10 | 2.1E-10 | 1.5 | 3.1E-11 | 1.5 | 3.1E-11 | 1 | 3.3E-10 |
| – Other native wild flora and products | kg/y | 1.5 | 6.0E-11 | 1.5 | 6.0E-11 | 1.5 | 6.0E-11 | 10 | 4.0E-10 | 1.5 | 6.0E-11 | 1.5 | 6.0E-11 | 1 | 6.2E-10 |
| Animal product consumption: | | | | | | | | | | | | | | | |
| – Cattle meat | kg/y | 69.3 | 1.0E-11 | 207.9 | 3.0E-11 | 69.3 | 1.0E-11 | 69.3 | 1.0E-11 | 69.3 | 1.0E-11 | 69.3 | 1.0E-11 | 29.5 | 6.6E-11 |
| – Cattle offal | kg/y | 4.5 | 2.3E-13 | 13.5 | 6.8E-13 | 4.5 | 2.3E-13 | 4.5 | 2.3E-13 | 4.5 | 2.3E-13 | 4.5 | 2.3E-13 | 0.6 | 4.7E-13 |
| – Cows milk | kg/y | 248 | 4.5E-11 | 744 | 1.3E-10 | 248 | 4.5E-11 | 248 | 4.5E-11 | 248 | 4.5E-11 | 248 | 4.5E-11 | 159.9 | 4.5E-10 |
| – Wild animal meat | kg/y | 8.75 | 2.2E-10 | 8.75 | 2.2E-10 | 8.75 | 2.2E-10 | 25 | 6.3E-10 | 8.75 | 2.2E-10 | 8.75 | 2.2E-10 | 4.5 | 1.8E-09 |
| – Wild bird meat | kg/y | 8.75 | 1.3E-10 | 8.75 | 1.3E-10 | 8.75 | 1.3E-10 | 25 | 3.6E-10 | 8.75 | 1.3E-10 | 8.75 | 1.3E-10 | 8.75 | 2.0E-09 |
| Fish consumption from lake | kg/y | 2.3 | 2.3E-12 | 2.3 | 2.3E-12 | 2.3 | 2.3E-12 | 2.3 | 2.3E-12 | 6.9 | 7.0E-12 | 2.3 | 2.3E-12 | 0 | 0.0E+00 |
| Soil consumption (not on crops): | | | | | | | | | | | | | | | |
| – from arable land | kg/y | 0.0055 | 1.9E-17 | 0 | 0.0E+00 | 0.0025 | 8.5E-18 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0.0025 | 8.5E-18 | 0.037 | 1.9E-15 |
| – from grassland | kg/y | 0 | 0.0E+00 | 0.0055 | 1.3E-16 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | kg/y | 0.0015 | 1.3E-15 | 0.0015 | 1.3E-15 | 0.0007 | 6.2E-16 | 0.0021 | 1.9E-15 | 0.0007 | 6.2E-16 | 0.0007 | 6.2E-16 | 0 | 0.0E+00 |
| – from wetland | kg/y | 0.001 | 8.1E-16 | 0.001 | 8.1E-16 | 0.0004 | 3.2E-16 | 0.0014 | 1.1E-15 | 0.0004 | 3.2E-16 | 0.0004 | 3.2E-16 | 0 | 0.0E+00 |
| – from river | kg/y | 0.0002 | 5.7E-17 | 0.0002 | 5.7E-17 | 0.0001 | 2.9E-17 | 0.0001 | 2.9E-17 | 0.0001 | 2.9E-17 | 0.0001 | 2.9E-17 | 0 | 0.0E+00 |
| – from lake | kg/y | 0.0002 | 7.9E-16 | 0.0002 | 7.9E-16 | 0.0001 | 3.9E-16 | 0.0001 | 3.9E-16 | 0.0025 | 9.9E-15 | 0.0001 | 3.9E-16 | 0 | 0.0E+00 |
| External from soil: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2920 | 5.6E-17 | 0 | 0.0E+00 | 2920 | 5.6E-17 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 5.6E-17 | 4383 | 8.5E-17 |
| – from grassland | h/y | 0 | 0.0E+00 | 2922 | 4.0E-16 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 4.5E-15 | 777 | 4.5E-15 | 777 | 4.5E-15 | 2530 | 1.5E-14 | 777 | 4.5E-15 | 777 | 4.5E-15 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 2.8E-15 | 516 | 2.8E-15 | 516 | 2.8E-15 | 1682 | 9.3E-15 | 516 | 2.8E-15 | 516 | 2.8E-15 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 1.6E-16 | 81 | 1.6E-16 | 81 | 1.6E-16 | 81 | 1.6E-16 | 81 | 1.6E-16 | 81 | 1.6E-16 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 2.4E-15 | 88 | 2.4E-15 | 88 | 2.4E-15 | 88 | 2.4E-15 | 3007 | 8.1E-14 | 88 | 2.4E-15 | 0 | 0.0E+00 |
| External from immersion in water from lake | h/y | 25 | 2.9E-17 | 25 | 2.9E-17 | 25 | 2.9E-17 | 25 | 2.9E-17 | 100 | 1.2E-16 | 25 | 2.9E-17 | 0 | 0.0E+00 |
| Inhalation of dust | | | | | | | | | | | | | | | |
| During normal activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2472 | 2.4E-18 | 0 | 0.0E+00 | 2472 | 2.4E-18 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 2.8E-18 | 4383 | 1.3E-17 |
| – from grassland | h/y | 0 | 0.0E+00 | 2586 | 1.8E-17 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 1.8E-15 | 777 | 1.8E-15 | 777 | 1.8E-15 | 2530 | 5.9E-15 | 777 | 1.8E-15 | 777 | 1.8E-15 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 1.1E-15 | 516 | 1.1E-15 | 516 | 1.1E-15 | 1682 | 3.6E-15 | 516 | 1.1E-15 | 516 | 1.1E-15 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 7.5E-17 | 81 | 7.5E-17 | 81 | 7.5E-17 | 81 | 7.5E-17 | 81 | 7.5E-17 | 81 | 7.5E-17 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 1.1E-15 | 88 | 1.1E-15 | 88 | 1.1E-15 | 88 | 1.1E-15 | 3007 | 3.8E-14 | 88 | 1.1E-15 | 0 | 0.0E+00 |
| During hard physical activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 448 | 3.6E-17 | 0 | 0.0E+00 | 448 | 3.6E-17 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from grassland | h/y | 0 | 0.0E+00 | 336 | 1.9E-16 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Inhalation of aerosols/spray: | | | | | | | | | | | | | | | |
| – from river | h/y | 81 | 7.8E-20 | 81 | 7.8E-20 | 81 | 7.8E-20 | 81 | 7.8E-20 | 81 | 7.8E-20 | 81 | 7.8E-20 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 1.5E-19 | 88 | 1.5E-19 | 88 | 1.5E-19 | 88 | 1.5E-19 | 3007 | 5.0E-18 | 88 | 1.5E-19 | 0 | 0.0E+00 |
| Total | | | 6.9E-09 | | 7.0E-09 | | 6.9E-09 | | 2.1E-08 | | 6.9E-09 | | 6.9E-09 | | 5.9E-08 |

# TABLE C81. EXPOSURE GROUP RESULTS FOR Nb-94 AT EQUILIBRIUM

| \Pathway | Exposure units | Results for Exposure Groups | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Arable Farmer | | Livestock farmer | | Horticultural producer | | Gamekeeper | | Fisherman | | Villager | | Infant | |
| | | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y | Exposure | Dose, Sv/y |
| Crop consumption: | | | | | | | | | | | | | | | |
| – Green vegetables | kg/y | 49.5 | 7.5E-12 | 49.5 | 7.5E-12 | 148.5 | 2.3E-11 | 49.5 | 7.5E-12 | 49.5 | 7.5E-12 | 49.5 | 7.5E-12 | 29 | 3.9E-11 |
| – Root vegetables | kg/y | 316.5 | 2.9E-10 | 105.5 | 9.6E-11 | 316.5 | 2.9E-10 | 105.5 | 9.6E-11 | 105.5 | 9.6E-11 | 105.5 | 9.6E-11 | 51.6 | 4.2E-10 |
| – Grain | kg/y | 471 | 2.8E-10 | 157 | 9.2E-11 | 157 | 9.2E-11 | 157 | 9.2E-11 | 157 | 9.2E-11 | 157 | 9.2E-11 | 14.8 | 7.7E-11 |
| – Wild fungi | kg/y | 6 | 9.8E-11 | 6 | 9.8E-11 | 6 | 9.8E-11 | 18 | 2.9E-10 | 6 | 9.8E-11 | 6 | 9.8E-11 | 3 | 4.3E-10 |
| – Wild fruit | kg/y | 45 | 3.7E-10 | 45 | 3.7E-10 | 45 | 3.7E-10 | 135 | 1.1E-09 | 45 | 3.7E-10 | 45 | 3.7E-10 | 33.6 | 2.4E-09 |
| – Wild nuts | kg/y | 1.5 | 1.2E-11 | 1.5 | 1.2E-11 | 1.5 | 1.2E-11 | 10 | 8.1E-11 | 1.5 | 1.2E-11 | 1.5 | 1.2E-11 | 1 | 7.2E-11 |
| – Other native wild flora and products | kg/y | 1.5 | 2.5E-11 | 1.5 | 2.5E-11 | 1.5 | 2.5E-11 | 10 | 1.7E-10 | 1.5 | 2.5E-11 | 1.5 | 2.5E-11 | 1 | 1.5E-10 |
| Animal product consumption: | | | | | | | | | | | | | | | |
| – Cattle meat | kg/y | 69.3 | 3.5E-12 | 207.9 | 1.0E-11 | 69.3 | 3.5E-12 | 69.3 | 3.5E-12 | 69.3 | 3.5E-12 | 69.3 | 3.5E-12 | 29.5 | 1.3E-11 |
| – Cattle offal | kg/y | 4.5 | 2.8E-12 | 13.5 | 8.4E-12 | 4.5 | 2.8E-12 | 4.5 | 2.8E-12 | 4.5 | 2.8E-12 | 4.5 | 2.8E-12 | 0.6 | 3.3E-12 |
| – Cows milk | kg/y | 248 | 2.9E-14 | 744 | 8.8E-14 | 248 | 2.9E-14 | 248 | 2.9E-14 | 248 | 2.9E-14 | 248 | 2.9E-14 | 159.9 | 1.7E-13 |
| – Wild animal meat | kg/y | 8.75 | 6.9E-12 | 8.75 | 6.9E-12 | 8.75 | 6.9E-12 | 25 | 2.0E-11 | 8.75 | 6.9E-12 | 8.75 | 6.9E-12 | 4.5 | 3.1E-11 |
| – Wild bird meat | kg/y | 8.75 | 1.5E-11 | 8.75 | 1.5E-11 | 8.75 | 1.5E-11 | 25 | 4.3E-11 | 8.75 | 1.5E-11 | 8.75 | 1.5E-11 | 8.75 | 1.3E-10 |
| Fish consumption from lake | kg/y | 2.3 | 6.6E-11 | 2.3 | 6.6E-11 | 2.3 | 6.6E-11 | 2.3 | 6.6E-11 | 6.9 | 2.0E-10 | 2.3 | 6.6E-11 | 0 | 0.0E+00 |
| Soil consumption (not on crops): | | | | | | | | | | | | | | | |
| – from arable land | kg/y | 0.0055 | 1.7E-12 | 0 | 0.0E+00 | 0.0025 | 7.9E-13 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0.0025 | 7.9E-13 | 0.037 | 1.0E-10 |
| – from grassland | kg/y | 0 | 0.0E+00 | 0.0055 | 2.0E-12 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | kg/y | 0.0015 | 3.7E-12 | 0.0015 | 3.7E-12 | 0.0007 | 1.7E-12 | 0.0021 | 5.2E-12 | 0.0007 | 1.7E-12 | 0.0007 | 1.7E-12 | 0 | 0.0E+00 |
| – from wetland | kg/y | 0.001 | 2.4E-12 | 0.001 | 2.4E-12 | 0.0004 | 9.6E-13 | 0.0014 | 3.4E-12 | 0.0004 | 9.6E-13 | 0.0004 | 9.6E-13 | 0 | 0.0E+00 |
| – from river | kg/y | 0.0002 | 1.6E-13 | 0.0002 | 1.6E-13 | 0.0001 | 7.8E-14 | 0.0001 | 7.8E-14 | 0.0001 | 7.8E-14 | 0.0001 | 7.8E-14 | 0 | 0.0E+00 |
| – from lake | kg/y | 0.0002 | 1.5E-13 | 0.0002 | 1.5E-13 | 0.0001 | 7.7E-14 | 0.0001 | 7.7E-14 | 0.0025 | 1.9E-12 | 0.0001 | 7.7E-14 | 0 | 0.0E+00 |
| External from soil: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2920 | 1.6E-07 | 0 | 0.0E+00 | 2920 | 1.6E-07 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 1.6E-07 | 4383 | 2.3E-07 |
| – from grassland | h/y | 0 | 0.0E+00 | 2922 | 1.8E-07 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 3.7E-07 | 777 | 3.7E-07 | 777 | 3.7E-07 | 2530 | 1.2E-06 | 777 | 3.7E-07 | 777 | 3.7E-07 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 2.5E-07 | 516 | 2.5E-07 | 516 | 2.5E-07 | 1682 | 8.3E-07 | 516 | 2.5E-07 | 516 | 2.5E-07 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 1.3E-08 | 81 | 1.3E-08 | 81 | 1.3E-08 | 81 | 1.3E-08 | 81 | 1.3E-08 | 81 | 1.3E-08 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 1.4E-08 | 88 | 1.4E-08 | 88 | 1.4E-08 | 88 | 1.4E-08 | 3007 | 4.7E-07 | 88 | 1.4E-08 | 0 | 0.0E+00 |
| External from immersion in water from lake | h/y | 25 | 1.4E-12 | 25 | 1.4E-12 | 25 | 1.4E-12 | 25 | 1.4E-12 | 100 | 5.7E-12 | 25 | 1.4E-12 | 0 | 0.0E+00 |
| Inhalation of dust | | | | | | | | | | | | | | | |
| During normal activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 2472 | 6.3E-12 | 0 | 0.0E+00 | 2472 | 6.3E-12 | 0 | 0.0E+00 | 0 | 0.0E+00 | 2919 | 7.4E-12 | 4383 | 1.3E-11 |
| – from grassland | h/y | 0 | 0.0E+00 | 2586 | 7.4E-12 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from shrubland | h/y | 777 | 1.8E-11 | 777 | 1.8E-11 | 777 | 1.8E-11 | 2530 | 5.7E-11 | 777 | 1.8E-11 | 777 | 1.8E-11 | 0 | 0.0E+00 |
| – from wetland | h/y | 516 | 1.2E-11 | 516 | 1.2E-11 | 516 | 1.2E-11 | 1682 | 3.9E-11 | 516 | 1.2E-11 | 516 | 1.2E-11 | 0 | 0.0E+00 |
| – from river | h/y | 81 | 6.1E-13 | 81 | 6.1E-13 | 81 | 6.1E-13 | 81 | 6.1E-13 | 81 | 6.1E-13 | 81 | 6.1E-13 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 6.5E-13 | 88 | 6.5E-13 | 88 | 6.5E-13 | 88 | 6.5E-13 | 3007 | 2.2E-11 | 88 | 6.5E-13 | 0 | 0.0E+00 |
| During hard physical activity: | | | | | | | | | | | | | | | |
| – from arable land | h/y | 448 | 9.5E-11 | 0 | 0.0E+00 | 448 | 9.5E-11 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| – from grassland | h/y | 0 | 0.0E+00 | 336 | 8.1E-11 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 | 0 | 0.0E+00 |
| Inhalation of aerosols/spray: | | | | | | | | | | | | | | | |
| – from river | h/y | 81 | 6.1E-19 | 81 | 6.1E-19 | 81 | 6.1E-19 | 81 | 6.1E-19 | 81 | 6.1E-19 | 81 | 6.1E-19 | 0 | 0.0E+00 |
| – from lake | h/y | 88 | 9.9E-19 | 88 | 9.9E-19 | 88 | 9.9E-19 | 88 | 9.9E-19 | 3007 | 3.4E-17 | 88 | 9.9E-19 | 0 | 0.0E+00 |
| Total | | | 8.1E-07 | | 8.3E-07 | | 8.1E-07 | | 2.1E-06 | | 1.1E-06 | | 8.1E-07 | | 2.4E-07 |

TABLE C82. GROUNDWATER SOURCE TERM TO EACH HABITAT AREA, EXPRESSED IN BOTH VOLUME ($m^3$ $y^{-1}$) AND DEPTH (m $y^{-1}$)

| Habitat Area | Area ($m^2$) | Depth of Groundwater Influx (m $y^{-1}$) | Volume of Groundwater Influx ($m^3$ $y^{-1}$) |
|---|---|---|---|
| Arable | 1.2E6 | 0.2 | 2.3E+05 |
| Grassland | 6.2E5 | 0.4 | 2.5E+05 |
| Shrubland | 3.9E5 | 0.4 | 1.6E+05 |
| Wetland | 2.6E5 | 0.4 | 1.0E+05 |
| River | 2.6E3 | 0.1 | 2.6E+02 |
| Lake | 2.5E5 | 0.1 | 2.5E+04 |

TABLE C83. SUMMARY RESULTS FOR EACH EXPOSURE GROUP FOR SEPARATE RELEASE INTO EACH HABITAT

| Radionuclide | Habitat | Arable Farmer | Livestock Farmer | Horticulture | Gamekeeper | Fisherman | Villager |
|---|---|---|---|---|---|---|---|
| I-129 | Arable | 7.9E-10 | 1.5E-09 | 7.8E-10 | 1.0E-09 | 1.2E-09 | 7.6E-10 |
| | Grassland | 3.2E-09 | 3.9E-09 | 3.2E-09 | 8.5E-09 | 3.7E-09 | 3.2E-09 |
| | Shrubland | 4.0E-09 | 4.3E-09 | 4.0E-09 | 1.2E-08 | 4.3E-09 | 3.9E-09 |
| | Wetland | 5.0E-10 | 7.1E-10 | 4.9E-10 | 1.4E-09 | 7.1E-10 | 4.9E-10 |
| | River lake | 1.1E-10 | 1.4E-10 | 9.7E-11 | 1.1E-10 | 1.8E-10 | 8.3E-11 |
| | Total | 8.6E-09 | 1.1E-08 | 8.6E-09 | 2.3E-08 | 1.0E-08 | 8.4E-09 |
| Np-237 | Arable | 1.5E-09 | 2.2E-09 | 1.5E-09 | 3.7E-09 | 1.8E-09 | 1.3E-09 |
| | Grassland | 2.3E-08 | 2.3E-08 | 2.3E-08 | 6.8E-08 | 2.3E-08 | 2.3E-08 |
| | Shrubland | 3.2E-08 | 3.2E-08 | 3.2E-08 | 9.7E-08 | 3.2E-08 | 3.2E-08 |
| | Wetland | 1.4E-08 | 1.4E-08 | 1.4E-08 | 7.7E-08 | 1.4E-08 | 1.4E-08 |
| | River lake | 4.9E-10 | 3.2E-10 | 4.8E-10 | 1.0E-09 | 1.2E-09 | 3.1E-10 |
| | Total | 7.1E-08 | 7.2E-08 | 7.1E-08 | 2.5E-07 | 7.2E-08 | 7.1E-08 |
| Tc-99 | Arable | 1.7E-10 | 2.2E-10 | 1.6E-10 | 4.1E-10 | 1.6E-10 | 1.6E-10 |
| | Grassland | 2.7E-09 | 2.7E-09 | 2.7E-09 | 8.1E-09 | 2.7E-09 | 2.7E-09 |
| | Shrubland | 3.8E-09 | 3.8E-09 | 3.8E-09 | 1.2E-08 | 3.8E-09 | 3.8E-09 |
| | Wetland | 1.9E-10 | 1.9E-10 | 1.9E-10 | 7.6E-10 | 1.9E-10 | 1.9E-10 |
| | River lake | 5.9E-12 | 5.0E-12 | 5.1E-12 | 9.4E-10 | 4.4E-12 | 4.1E-12 |
| | Total | 6.9E-09 | 6.9E-09 | 6.9E-09 | 2.2E-08 | 6.9E-09 | 6.9E-09 |
| Nb-94 | Arable | 7.5E-08 | 1.3E-07 | 7.5E-08 | 6.5E-08 | 1.6E-07 | 7.5E-08 |
| | Grassland | 2.0E-07 | 2.2E-07 | 2.0E-07 | 4.9E-07 | 2.9E-07 | 2.0E-07 |
| | Shrubland | 2.7E-07 | 2.4E-07 | 2.7E-07 | 7.5E-07 | 3.3E-07 | 2.7E-07 |
| | Wetland | 2.5E-07 | 2.3E-07 | 2.5E-07 | 7.4E-07 | 2.9E-07 | 2.5E-07 |
| | River lake | 2.0E-08 | 8.1E-09 | 2.0E-08 | 1.4E-08 | 5.0E-08 | 2.0E-08 |
| | Total | 8.2E-07 | 8.3E-07 | 8.2E-07 | 2.1E-06 | 1.1E-06 | 8.2E-07 |

# C5. EXAMPLE REFERENCE BIOSPHERE 3

## C5.1. INTRODUCTION

According to the particular circumstances in which the assessment is made, it may be appropriate to follow simple or more complex approaches in addressing the biosphere. The series of Example Reference Biospheres explored in BIOMASS Theme 1 has been designed to give consideration to a range of issues that are of potential interest in the context of solid radioactive waste disposal for a variety of hypothetical assessment contexts. Very simple assessment biospheres are potentially open to criticism for being too coarse a representation of the features, events and processes that can be relevant to determining the radiological significance of projected releases in the long term. However, the incorporation of additional complexity, with the objective of addressing such concerns, can introduce other difficulties. For example, it is necessary to consider whether the information requirements and related uncertainties associated with more complex assessment biospheres are in proportion to their role in contributing to safety assurance.

Clearly, any assessment biosphere, however complex, can do no more than provide an indicator of the level of protection provided by a disposal system in the long term. The purpose of BIOMASS Theme 1 Examples is to inform discussion of the potential implications of addressing different levels of complexity in biosphere assessments for solid radioactive waste disposal and their value as a guide to decision making.

ERB1 was developed by restricting consideration in definition of the assessment biosphere to a single transfer and exposure pathway (drinking water from a well). This resulted in a simple conceptual and mathematical model, with relatively few data requirements that are easy to support and justify, under conservative assumptions. However, various previous assessments have demonstrated that exposure pathways other than drinking water can also make an important contribution to individual exposures.

The cases investigated as ERB2A and 2B address a wider range of environments, giving rise to multiple transfer and exposure pathways, under the assumption of constant biosphere conditions. 'Constant' in this case means that characteristics of the principal components of the biosphere system are assumed to be invariant over the period in which contaminants released into the system achieve equilibrium concentration levels in environmental media. ERB2A involves the assumption that water resources for domestic and agricultural purposes are obtained via a well drilled into the underlying regional aquifer. By contrast, ERB2B invokes more complex considerations by assuming that contamination enters the biosphere via groundwater in a region of natural discharge. Agricultural and semi-natural environments are considered, but still under constant biosphere conditions.

The particular focus of ERB3, is to demonstrate the scheme developed as part of the BIOMASS Methodology for considering the implications of changes that may occur within the biosphere system during the period in which a release from the disposal facility could occur. Part B describes enhancements to the procedure for the treatment of biosphere change within the overall BIOMASS Methodology, ERB3 illustrates the approach, reflecting concerns that the relevant features of a particular region, its climate and landscape may need to be factored into the siting, design and safety assessment for a particular facility. Three sub-Examples are examined, based on available information relating to previous studies. Two relate to demonstration performance assessments for hypothetical disposal facilities at Äspö in Sweden and Harwell in United Kingdom. The third applies to a non specific site, corresponding to ERB2A, and explores general implications of a particular Global Climate sequence.

It is emphasised that the aim of the examples is to make use of readily accessible data in order to be able to reflect more generally on the value of site-specific information in describing change within the framework of the BIOMASS Methodology. It has not been the aim to follow the complete Methodology through to the calculation of individual doses. Instead, the goals are limited to an analysis of how change can be considered, and to reflecting on the value of such approaches in providing an adequate representation of potential radiological impact in future environmental conditions.

Assessment contexts for all the Example Reference Biospheres focus attention on specific issues of particular practical interest to long-term assessments. The aim is that they should provide a realistic basis for structuring the development of each Example, consistent with the overall systematic approach.

For a ‘real’ safety assessment, the primary consideration in justifying how a particular assessment biosphere has been defined and used is its fitness for purpose. This means that the underlying purpose of the assessment is necessarily the chief point of reference for identifying and describing appropriate biosphere system(s) and related assessment model(s). Other aspects of the assessment context then come into play by defining specific technical objectives, consistent with the overall purpose (BIOMOVS II, 1999). A combination of multiple lines of reasoning, potentially involving different levels and types of detail and/or complexity, will often be required to build confidence in the overall performance assessment.

## C5.2. OVERALL ASSESSMENT CONTEXT

The assumed assessment context is summarised as below for all three sub-Examples in Example 3:

| | |
|---|---|
| Assessment Purpose: | Regulatory Compliance<br>Regulator/Scientific Confidence<br>Guide to Site Selection<br>Proof of Concept<br>Guide Biosphere Research Priorities |
| Assessment Endpoint: | Annual individual effective dose |
| Repository Type: | Deep repository for long-lived solid radioactive waste |
| Assessment Philosophy: | ‘Equitable’ except with respect to the critical group definition, which should invoke a ‘cautious’ approach |
| Site Context: | Hypothetical repository locations at Äspö (Sweden) and Harwell (UK), as well as a hypothetical site corresponding to the assumptions adopted for ERB2A. |
| Geosphere-Biosphere Interface: | May vary with time as a result of biosphere system change, with concentrations of radionuclides in groundwater discharge to the surface environment assumed to be provided by groundwater transport models. |
| Source Term: | Wide range of radionuclides identified as relevant to long-term radiological safety assessments, including Tc-99, I-129 |

| | |
|---|---|
| | and Np-237. For practical reasons, in the absence of system-specific source term information, it is assumed that concentrations in groundwater are maintained indefinitely at unit values. |
| Societal Assumptions: | Local community is initially the same as that defined in the site context for the present day, but is anticipated to adapt in order to accommodate biosphere system change, in a manner consistent with that in present-day analogue regions. |
| Time Frame: | Up to 1 million years. |

In summary, the BIOMASS Methodology for addressing biosphere change is as follows:

(1) Review Assessment Context;

(2) Identify mechanisms causing environmental change; and

(3) Identify the impacts of change on the biosphere system, through:

- Description of the present day regional biosphere system (according to the standard list of 'biosphere system components');
- Screening of mechanisms of change for relevance to the site context under the following general headings:

  Climate-induced change;

  Geological change;

  Human-induced change.

  This provides a context specific version of a generic influence diagram, with the 'screened out' external FEPs (EFEP) removed.

- Description of the long-term evolution of the regional landscape under the influence of the remaining EFEPs (perhaps with one or more variant interpretations), based on baseline descriptions of global mechanisms.
- Split the sequence of landscape change into 'snapshots', based on the system state before and after (or, for short-term change, during) what are considered to be radiologically-significant transitions. Each snapshot provides a regional-scale description of the biosphere system based on the standard 'system component' headings, taking account of interactions between system components affected by external mechanisms of change. Each system description is also provided with associated assessment context information for the source term and geosphere-biosphere interface.
- Identify relevant 'assessment biospheres' associated with each landscape snapshot, taking into account projected changes in the source term and geosphere-biosphere interface within the evolving landscape.
- Finally, based on arguments relating to the projected behaviour of radionuclides in the evolving biosphere, consider the potential advantages and disadvantages of explicit simulation of transitions.

## C5.3. ASSUMED GLOBAL CLIMATE CHANGE IN THE TIME FRAME OF INTEREST

Alternative time sequences for future global climate change and associated changes in continental ice sheets and global sea level are defined, as a precursor for describing regional landscape response. However, it is worth noting that, despite substantial scientific consensus regarding the important factors, major uncertainties remain regarding the detailed characterisation of such changes. Moreover, there are possible non-linear effects (such as changes to the oceanic thermo-haline circulation) that could have major impacts on climate change, particularly on a regional scale.

Nevertheless, two primary representations of the forecast time sequence of global climate change are assumed here, to provide a common basis for the development of biosphere system descriptions for each of the Examples. It is recognised that alternative assumptions, covering a broader range of uncertainty, might have been examined, but those described here provide a practical basis for comparing the different outcomes in each case.

### C5.3.1. Climate change Scenario 1

The standard glacial-interglacial cycling model (based on the palæoclimate record), indicates a progressive cooling in global temperature from the present day over a period of some 25 000 years to the next glacial maximum. At this time, mean global surface temperatures are anticipated to be in the region of 8 to 10° C cooler than at present. This is followed by a post-glacial warming period of some 10 000 years, during which time temperatures recover to somewhat (c.3 to 5° C) below present-day values. The cycle then enters another cooling phase, achieving a further, more extreme glacial maximum (some 12 to 15° C cooler than at present) at approximately 60 000 years after present.

This glacial maximum, is in turn, followed by a further warming period (again over approximately 10 000 years), although global temperature remains some 5° C or more cooler than present-day values, even at the maximum. Progressive cooling leading to a further glacial period is then anticipated, with the minimum in global temperature occurring sometime beyond 100 000 years. Beyond this glacial period, extrapolation of the palæoclimate record indicates a recovery in global temperatures to interstadial values similar to those of the present, and the cycle is repeated.

During the cooling periods, the continental ice sheets increase in volume and there is an associated fall in global sea level. At 25 000 years, global sea level is estimated to be in the region of 80 m below its present-day level, which is slightly below the long-term average (estimated at -70 m) over the late Quaternary period (i.e. from 500 000 years before present up to the present day). Sea level recovers with the melting of continental ice sheets during warmer episodes; however, there may be time lags of as much as 5 000 years, such that global temperatures slightly cooler than at present may occur with substantially reduced global sea levels.

At approximately 25 000 years, the continental ice sheets of the Northern Hemisphere are not very extensive compared with their estimated maximum volumes during the Quaternary period. In particular, although there may be some localised glaciation in more mountainous regions at intermediate latitudes, the Fenno-Scandian ice sheet is not expected to extend much further south than approximately 60°N.

At the next glacial maximum (some 60 000 years after present) the Fenno-Scandian ice sheet is estimated to cover much of Scandinavia and the northern United Kingdom. However, it does not extent into continental Europe, although valley glaciers may be an increasingly important feature of more mountainous areas. Beyond 100 000 years, much of the Baltic and North Sea regions, as well as a substantial proportion of the present-day land mass of the United Kingdom, is expected to be ice-covered. Palæoclimate records indicate that global sea level at the time of the last glacial maximum were some 120-130 m below those of the present day.

### C5.3.2. Climate change Scenario 2

The greenhouse-warmed model (based on projections using global circulation models) indicates a progressive warming in temperature beyond the current maximum in the glacial-interglacial cycle. Global surface temperatures are estimated to reach some 2 to 3ºC above present-day average values over a period of a few hundred years, achieving a maximum of 6ºC higher at approximately 10 000 years. Beyond this, however, the driving forces responsible for glacial-interglacial cycling are assumed to take control, and there is progressive cooling until present-day global temperatures are recovered at approximately 15 000 to 20 000 years after present.

Global temperatures are then predicted to continue to fall, estimated to coincide with those predicted by the standard glacial-interglacial cycling model at around the time of the 'warmer' interglacial episode approximately 35 000 years after present. Global temperatures then continue to fall towards the glacial maximum (12 to 15°C cooler than at present) at approximately 60 000 years after present.

There is no scientific consensus regarding how sea level is likely to respond to a greenhouse-warmed world. However, it is typically assumed that there would only be limited melting of continental ice sheets and valley glaciers for the first few degrees of global temperature rise. The stability of the Antarctic ice sheet to global temperature rise is uncertain, but in some projections there is potential for sea-level fall as a result of increased ice accretion from evaporation of the southern oceans falling as snow on the East Antarctic plateau. As temperatures increase further, thermal expansion of the oceans and the loss of the Greenland ice sheet is estimated to give rise to a total sea level rise in the region of 3 to 7 m, for a global temperature some 6° C higher than at present. Collapse of the West Antarctic ice sheet would give rise to similar increases in sea level (Thorne et al., 2000). Nevertheless, major increases in global sea level (by several metres) are not therefore anticipated until global temperatures are several degrees above those of today.

The post greenhouse-warmed cooling phase begins with much-reduced ice volume in the Greenland and Antarctic ice sheets. Their re-growth is expected to lag behind the temperature fall by around 5 000 years, which implies that temperatures similar to those of today may be recovered with global sea levels that are 5 to 10 m above those of the present day. The main controlling factors on global ice volume and sea level in cooler episodes are the initiation and growth of the Laurentide (North American) and Fenno-Scandinavian continental ice sheets. Beyond approximately 35 000 years after present, ice sheet growth and the changing global sea level are assumed to follow the same pattern as for the standard glacial-interglacial cycling model.

### C5.3.3. Application to the examples

Application of the above to the Examples has not been completed in full. However, the following sections do illustrate some of points. In the case of the Äspö sub-Example (Section C5.2), the assessment biospheres of interest are: (a) a set of equilibrium system states, corresponding to long-term terrestrial/marine biospheres; and (b) the specific transition from shallow marine => lake => terrestrial environment associated with isostatic land rise.

An important consideration at Harwell (Section C5.3) is the potential influence of cold climate processes on groundwater transport and, hence, on the location and dispersion of the release of radionuclides.

The focus in the remaining case (Section C5.4) based on ERB2A, is a general consideration of the potential relevant effects of climate change and the implications for selecting one or other system or transition between systems to evaluate their radiological significance.

## C5.4. ASPO SUB-EXAMPLE

### C5.4.1. Review of assessment context

*Climate and Atmosphere (Table CI[15]):* The most appropriate class for Äspö is *ZB VI* (typical temperate with a short period of frost). The mean annual temperature for the warmest month is about 15-18° C and mean values for the coldest is above -3° C.

*Geographical Extent and Topography (Table TI):* The site has the following characteristics.

- Geographical context: *coastal* – with archipelago. The site is located on the Swedish Baltic coast;
- Altitude: *lowland* – The topographical relief varies from –21 to +14 m above sea level and is characterised as a fissure valley landscape;
- Landform: *subdued*;
- Localised erosion: *limited localised erosion* – no significant erosion under present-day conditions.

*Human Activity (Table HI):* Using data from Lindborg and Schüldt (1998), the current type of human activity in the area of the site can be best described as *a coastal community based on mixed farming and fishing*. The area is very popular for recreation purposes and summerhouses are frequent. Some minor industries are in the area and the largest technical facility is Simpevarp nuclear power plant.

*Near-Surface Lithostratography (Tables GI, SI and RTI):* The rock type is classed as igneous as it is heterogeneous, dominated by Smålands granite, with high degree of exposed rock (SKB, 1999). The land surface has a high proportion of outcrops, and the deposits in the depressions are thin (0–5 m). The deposits are dominated by wave-washed bouldery till that is sometimes overlain by thin sand and clay strata. In the coastal bays, the till is overlain with mud deposit. The cover is composed of Quaternary sediments, mainly moraine, and the terrain is rocky. The most common soil units in the region are lithosols, with some occurrence of luvi-cambisols, Table 7 in NMR (1984).

*Water Bodies (Table WI): Brackish water with bays* is common in the area of the site. Some *small streams* are present and *there are mires on the islands*. A few *drilled wells* are in the area.

[15] Table references are to Tables in Annex BI of Part B.

*Biota (Table BI):* The sea areas are classed as *brackish ecosystems*, rich in vegetation (reeds) and soft sediment bottoms, which run close to the surface, where occasional rock outcrops occur. Owing to the low salinity, freshwater vegetation probably dominates; freshwater animals probably dominate the fauna in the bays with various insect larvae in the sediments. There may possibly be populations of Baltic Sea mussels in the soft bottoms. The fish population consists solely of freshwater fish such as perch and pike but also Baltic herring.

The terrestrial system in the area of the site is essentially a semiboreal *forest ecosystem*. Only about 7 % of the land area is used for agricultural purposes, especially for grazing.

### C5.4.2. Identification of mechanisms causing environmental changes

TABLE C84. MECHANISMS CAUSING ENVIRONMENTAL CHANGES AND POTENTIAL IMPACTS ON THE BIOSPHERE SYSTEM FOR ÄSPÖ EXAMPLE

| Change | Impacts on system, to be considered further |
|---|---|
| CLIMATE | |
| Global climate change | Global effects are important and may change the system completely. |
| Isostacy/eustacy | Land rise/isostacy occurs at Äspö, and is expressed through change of land/water distribution. It is not believed that there are any direct effects (e.g. change of rain shadow) and therefore it is not considered relevant to regional climate change. |
| Volcanics | Not a specific regional climate issue at this site |
| Surface nature | Land rise/isostacy will cause water bodies to disappear. Amplitude of temperature variation will increase as the distance to coast increases. Considered that local effects of encroaching ice sheets are captured in the discussion of global climate. |
| Land use | Affects surface nature – but can not be seen as direct effect on climate. |
| Thermal pollution | Heat from the repository reaches the surface after a few hundred years. The heat will have a marginal impact on the thermal conditions on the ground surface. The effect is comparable to the natural geothermal heat flow, which is in turn less than a tenth of a percent of the heat input of sunshine (SKB, 1999). |
| Local atmosphere | Future human actions may give rise to microclimate effects through impacts on local atmosphere. This is always of potential interest at any site and a question to be addressed as part of the overall assessment strategy. This may be captured in any case as part of general consideration of human actions affecting the biosphere system |
| LONG-TERM LANDFORM | |
| Glacial denudation | Eventually a glacier will reach this site within the timeframe of interest. There may not perhaps be major influence on granitic rocks, but some decisions must be made in providing the ‘story’ of landform development at the site. It is known that, due to the former glaciation, there is a continuous regression of the shoreline. This effect may be even more pronounced initially in a cold climate period, because more water will be bound in frozen form. If the cooling continues, the growing ice will on the other hand press down the rock leading to an increase of the water level, see Figures C27(a) and C27(b). Shoreline displacement will lead to fundamental changes of the area. |
| Fluvial erosion | Not under current conditions – but maybe in the future (for example) in association with glacier meltwater. |
| Coastal erosion | It is occurring, but mainly it is moving material around within the system, not a major effect on the general landform. Perhaps more to do with the dynamics of the system than its development. |
| Aeolian erosion | Not under current conditions – and not really in the future, because any loose materials generated by glaciation will become submerged by the encroaching sea as the ice retreats. |
| Downcutting river-bed | May change local stream/river courses and therefore (perhaps) the regional hydrology regime. Not really so relevant as a process for changing the interface, or as a significant impact on topography. |
| Solifluxion | Potentially a relevant transport mechanism, but not a major landform development process at this site. |
| Sediment accretion | Infilling of lakes created in the bay areas of the archipelago. |

TABLE C84. MECHANISMS CAUSING ENVIRONMENTAL CHANGES AND POTENTIAL IMPACTS ON THE BIOSPHERE SYSTEM FOR ÄSPÖ EXAMPLE (CONT.)

| LONG-TERM LANDFORM | |
|---|---|
| Landslip/rockfall | No strong local gradients. |
| Isostacy and land rise | Important ongoing effect (and possible future effect) expressed as shore-line displacement. |
| Rock stress | Effects would be outside the domain of interest but there is a need to be sure that the domain of interest is well understood when the system is identified. |
| Intrusive/extrusive processes | Not important as a process at Äspö. Also, the effects would be outside the domain of interest for the biosphere system. |
| Solutional denudation | Granitic rock/moraine not very soluble - minor effect only. |

### C5.4.3. Impacts of change on the biosphere

In light of the discussion and screening documented in Table C84, it can be seen that the primary mechanisms causing environmental change at the Äspö site are associated with land-uplift, land filling and climate change. Major impacts are expected from long-term landform development processes since glaciation affects the site within the coming 10,000 years. In addition, for this specific example, the assessment context states that human society will change in response to environmental change, so human activities are interpreted to respond to climate change rather than driving it.

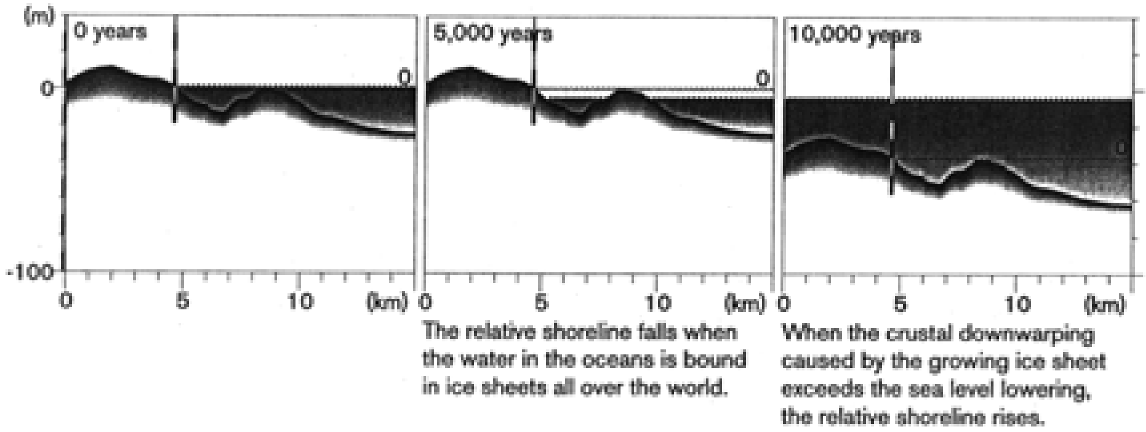



*FIG. C27(a). Evolution of the shoreline during the preglacial regime.*

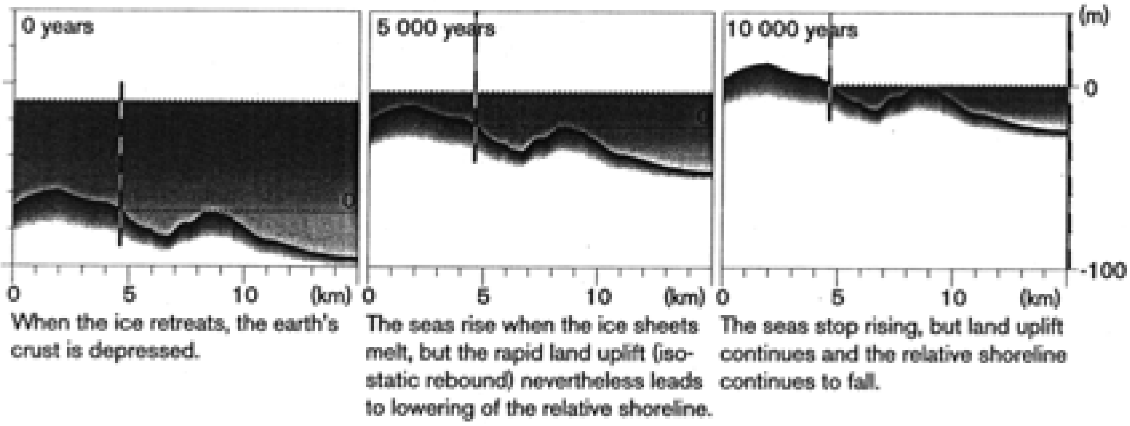



*FIG. C27(b). Evolution of the shoreline during the postglacial regime from (SKB, 1999).*

TABLE C85. MECHANISMS OF CHANGE AND THEIR IMPACTS ON THE BIOSPHERE SYSTEM FOR THE ÄSPÖ SITE EXAMPLE (SEE FOLLOWING TEXT FOR THE CONTENT OF EACH CELL)

| | Climate change | Landform development processes | Societal changes |
|---|---|---|---|
| Climate | 1.1 | 1.2 | 1.3 |
| Water bodies | 2.1 | 2.2 | 2.3 |
| Human activities | 3.1 | 3.2 | 3.3 |
| Biota | 4.1 | 4.2 | 4.3 |
| Near surface lithology | 5.1 | 5.2 | 5.3 |
| Topography | 6.1 | 6.2 | 6.3 |
| Geographical extent | 7.1 | 7.2 | 7.3 |
| Location | 8.1 | 8.2 | 8.3 |

1.1 Climate change on local climate: A climate scenario has been studied by use of descriptions of past climatic evolution, and on model calculations of future conditions. It is primarily intended to describe the evolution during the next 150,000 years, but, in essence describes climatic evolution during even longer time. The calculations performed show the following possibilities for the Äspö site from today until approximately 20,000–30,000 years in the future climate gets progressively colder. When it is coldest, the annual mean temperature at Äspö may be approximately –1º C, compared with today's 7ºC. The climate during this period is temperate/boreal with permafrost. Thereafter a warmer period and colder period follow with a successive increase of the area covered by ice, ending up with ice down to northern Poland and Germany at about 150 000 years.

In summary, except for short periods during interglacials, Äspö is a site that remains beneath the surface of the sea. Äspö is only ice-covered during the coldest periods of a glacial cycle. During less severe stadials, the ice front may lie at Äspö.

1.2 Climate affects landform development as a colder period may lead to increased regression followed by transgression as the ice cover will press on the rocks leading to a higher shoreline.

1.3 Societal change on climate: Local societal changes affect local climate. Could have aerosol processes and heat dome effects and vegetation changes. But these changes will probably only be small – they will not change the climate class group. Note that global climate impacts due to global human activities are covered under 1.1.

2.1 Climate change on water bodies. A new glaciation will increase the distribution between open water and land, so that it is possible that Äspö will be submerged for most of the coming 100 000 years. The growing ice cover leads to a rise in the shore-line as the growing icecover presses down the rock, see Figures C27(a) and C27(b) above. The climate will affect phase, turnover, volume, nature (frozen, unfrozen), as well as groundwater-surface water connectivity and flow.

2.2 Landform development processes on brackish waters: Landrise will cause former brackish water to be isolated to freshwater basins. This will occur during the coming 2500 years. (Land-rise caused the formation of the island Äspö). Thereafter the lakes may be transformed to wetlands. Thereafter the climate change will lead to submerging of areas. The following changes will be due to climate changes, which will then affect landform development.

2.3 Societal change on water bodies such as creation/destruction of water bodies: This is of minor importance for the Äspö site due to its low topography and the fact that natural development is of much more significance for the site.

3.1 Climate change on human activities:

— Nature of change: Nature of settlement (density, seasonal occupancy), habits.

— Spatial and temporal scales: Population might migrate into/out of the area.

3.2 Landform development processes on human activities:

— Influences settlements and habits. However the area will not be especially suitable for large agriculture practices.

3.3 Societal change on human activities: not applicable.

4.1 Climate change on biota:

— Nature of change: Composition of ecosystem (biomass, production, type of species).

4.2 Landform development processes on biota: changes brackish water ecosystems to freshwater ecosystems. These ecosystems may in turn be transformed to wet areas such as mires, peatbogs etc.

4.3 Societal change on biota:

— Composition of wild and domestic fauna and flora and associated productivity may change if forests are cut animals shot, large picking of berries, and the area for grazing may change.

5.1 Climate change on near-surface lithology:

— Nature of change: composition, structure, but there is the issue of whether there will be a significant change at least under boreal conditions, but perhaps there will be a more significant change under tundra conditions. The area of bare rocks may be enlarged due to glaciation and melting periods.

— Spatial and temporal scales: Not needed at present.

— Speed of response: In the order of 1000s of years.

5.2 Landform development processes on near-surface lithology: land rise has no direct effect but may be affected indirectly by erosion effects and ecological development. Glacial denudation may not influence the topography but may remove the till layer, down to 5 to 10 m.

5.3 Societal change on near-surface lithology:

— Nature of change: Soil management will cause changes in composition, structure, productivity. Note that the area is not so suitable for intensified agricultural practices.

— Speed of response: years to 10s of years.

6.1 Climate change on topography (depend on the definition of topography): major change for the Äspö site is that the distribution of surface water/land may change due to regression and transgression.

6.2 Landform development processes on topography (depend on the definition of topography):

— Nature of change: distribution of surface water/land area may change due to regression and transgression.

6.3 Societal change on topography: none, since the assessment context suggests that society responds to environmental change rather than driving it.

7.1 Climate change on geographical extent: no major change.

7.2 Landform development processes on geographical extent: no change.

7.3 Societal change on geographical extent: Note that for this example there is probably no change. (Note that there might be tendency for a more nomadic lifestyle, but this does not have an impact on the geographical extent for this assessment context because of the need to calculate individual dose rather than collective dose).

8.1 Climate change on location– the site will be successively transformed to open sea.

8.2 Landform development processes on location: the site will remain coastal though the distance to the coastline will increase.

8.3 Societal change on location: no change – the site will remain coastal.

## C5.5. HARWELL SUB-EXAMPLE

### C5.5.1. Review of assessment context

*Climate and Atmosphere (Table CI):* The most appropriate class for Harwell is *ZB VI* (typical temperate with a short period of frost). Data in Sumerling et al., (1992) show that there is a mild winter lasting three to four months during which frosts can occur. Average daily temperatures during the winter period rarely fall below freezing. The mean annual temperature is 9.5 °C and mean annual precipitation is 688.5 mm.

*Geographical Extent and Topography (Table TI):* The site has the following characteristics.

— Geographical context: *inland* – the site is located about 80 km from the sea.

— Altitude: *lowland* – the altitude in the region of the site ranges from less than 60 m in the Vale of the White Horse to 260 m on the Berkshire Downs.

— Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse which has low relief. To the south are the Berkshire Downs and the Chilterns which have rolling topography.

— Localised erosion: *limited localised erosion* – no significant erosion under present-day conditions.

*Human Activity (Table HI):* Using data from Sumerling et al., (1992), the current type of human activity in the area of the site can be best described as a *large-scale trading community type* with a wide range of community types/activities and associated level of biosphere management. Examples of both low and high levels of biosphere management can be found. Much of the rural region around the site is used for agriculture and horticulture with the production of crops (especially cereals and fruit) and animals (especially cattle). In addition, there are several large towns (such as Didcot and Abingdon), and some mineral exploitation (e.g. sand and gravel) and industrial landuse (e.g. coal fired power station and the Harwell nuclear research facility).

*Near-surface Lithostratography (Tables GI, SI and RTI):* Details of the underlying geology and in the region of the site are given in Sumerling et al., (1992). Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as *sedimentary*. CEC (1985) classifies the soils in the area around the site using the FAO classification scheme. Common soil types are *Eutric Glesols, Orthic Luvisols, Chromic Luvisols and Orthic Rendzinas*. Only the Chromic Luvisols are explicitly mentioned in Table SI.

*Water Bodies (Table WI):*

— *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*.

— With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.

— *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI):* Table BI classifies terrestrial and aquatic ecosystems as a function of their level of management. It should be noted that fauna and flora classified under biota are first defined using the ecosystem classification, which is more general. The detailed list of the components of the biota will be provided in the description of the biosphere systems. The streams and rivers might be considered to be *natural ecosystems*, but even they are often influenced by humans through the abstraction of water and discharge of sewage and other contaminants, so classification as *semi-natural aquatic ecosystems* might be more appropriate. Certainly, the reservoir is a *managed ecosystem*. The terrestrial system in the area of the site is essentially a *managed ecosystem*. In light of information given in Sumerling et al., (1992), all the managed terrestrial ecosystems listed in Table BI can be included with the exception of rough grassland.

### C5.5.2. Consideration of biosphere system change

The assessment context specifies that the biosphere system can be subject to change. Thus there is a need to identify and justify the mechanisms for change and their potential impacts on the biosphere system.

### C5.5.3. Identification of mechanisms causing environmental changes

The assessment context for this example states that the maximum time frame is one million years, which allows the exclusion of some of the climatic causes of change that operate on a larger time frame. The results of the discussion and associated screening are presented in Table C86.

In light of the discussion and screening documented in Table C86, it can be seen that the primary mechanisms causing environmental change at the Harwell site are associated with climate change; the effects of long-term landform development processes and human activities on the environment are secondary in comparison. Major impacts are expected from long-term landform development processes only if glaciation were considered to affect the site. In this case, the transition between the absence and the occurrence of glaciation would affect the landform evolution. In addition, for this specific example, the assessment context states that human society will change in response to environmental change, so human activities are interpreted as responding to climate change rather than as driving it.

From the above, it was noted that many of the causes of global climate change are closely coupled and it was difficult to separate the effects out from the causes. Furthermore, in going through the process of identifying and screening the mechanisms, it was found that it was necessary to give some initial consideration to the impacts associated with each of the mechanisms ahead of Step 2.2 in order to allow the significance of the mechanisms to be assessed.

TABLE C86. MECHANISMS CAUSING ENVIRONMENTAL CHANGES AND POTENTIAL IMPACTS ON THE BIOSPHERE SYSTEM FOR THE HARWELL SITE

| Change | Impacts on system, to be considered further |
|---|---|
| CLIMATE | |
| Solar variability | Affects global climate - short term will not be substantial (little ice age). Long term solar variability is an important factor and is integrated in Berger (LLN) model and has been downscaled to central England. |
| Earth orbit | Affects global climate. Also considered to be very important because of Milankovitch theory. |
| Isostacy | Affects local and global climate but its relative importance is small. Some potential of ice, especially at the margin of the site, but will cause a very limited isostatic depression. |
| Evolution of atmospheric composition | Affects global climate. Considered to be an important driver – vegetation patterns effect carbon dioxide emissions – and encompassed in LLN model to a certain extent in *ad hoc* empirical manner. |
| Volcanics | Will affect global climate, but not local climate at Harwell. Consideration of change from temperate to glacial conditions scopes the effects of volcanoes. |
| Tropospheric dust | Limited, very short term effects so not considered to be important. This mechanism should be included in volcanics. |
| Surface nature | Vegetation could affect local climate; other surface effects are covered elsewhere (depending on the climate models). The change will not affect the nature of the types of vegetation for example, however it may modify locally evapo-transpiration and hydrology characteristics. LLN model has considered many of these factors and their associated effects but only at the global level. Insolation variations alone are too weak to drive glacial cycles – need to consider feedback factors e.g. nature of the surface and the carbon dioxide composition of the atmosphere. |
| Atmos-Litho-Cryosphere | Locally variable. Linked to the feedback issue. Not certain about this mechanism, but even if important it is subsumed in the Milankovitch cycle approach with the range from temperate to glacial. |
| Atmosphere ocean feedback | Could have an impact for the system considered and there could be transient effects that might need to be considered (Adcock et al., 1997). Not subsumed into long term models due to lack of detailed ocean basin model. |
| Atmospheric auto variation | Too short a time frame to be of interest. |
| Land use | Vegetation effects, for this context. Could have some impact on local climate (see earlier discussion on effects of vegetation on climate e.g. impacts on albedo, deforestation impacts on local wind speeds and precipitation). Can be some global impacts e.g. global deforestation. |
| Greenhouse gases | Human induced changes could affect natural evolution of atmosphere. Greenhouse gases are a driver for global climate. Impact of sulphur emissions is more regional. Included before in the composition of the atmosphere category. |
| Thermal pollution | Repository heat could produce a gap in permafrost but not considered to be important if repository is at 300 m depth. Could this affect local climate? It could be important in influencing the temperature of the groundwater There could be knock-on effects on vegetation and therefore climate. Need more information concerning the thermal pollution from HLW repository – is it dominated by long term decay or short term decay? But how significant will this be for the Harwell site? Need to consider the flow rate of the water into which the heat flux is discharged. Note that the release at Harwell might discharge into a relatively minor aquifer. More general (non-repository) thermal pollution could be included in the composition of the atmosphere category above. |

TABLE C86. MECHANISMS CAUSING ENVIRONMENTAL CHANGES AND POTENTIAL IMPACTS ON THE BIOSPHERE SYSTEM FOR THE HARWELL SITE (CONTINUED)

| Change | Impacts on system, to be considered further |
|---|---|
| LONG-TERM LANDFORM | |
| Landform development processes (including erosion and deposition) | The key issue is whether there will be glaciation at the site. At the most extreme there might be glaciation of the site (as considered in the Dry Run 3 exercise) and an analogue site from the north east of Harwell could be used if required. However, there is evidence that no glaciation occurred at Harwell even with the greatest power ice sheet in the UK over the Quaternary, so it was decided not to consider glaciation for the first iteration of the procedure.<br>Harwell might therefore be an ice marginal site and affected by ice fore-bulge and some limited isostacy affects. Changes to geosphere-biosphere interface may occur. There might be solutional denudation (up to 10s of m per million years). Aeolian and fluvial denudation might not change the landscape significantly.<br>Other issues include the down cutting of the river due to sea level fall and its impact of groundwater discharge (via incision). Also the need to consider the impact of climate on the run-off/recharge regime in the chalk.<br>Based on Dry Run 3, the seasonality of the hydrology changes markedly but the overall impacts on landform are minor.<br>No inter or intra plate activity in the Harwell region so not considered to be important.<br>No field evidence for outwash deposits. But glaciation would suggest there might be outwash deposits. Also fluvio-glacial sedimentation. |
| Change in rock stress | Non issue for Harwell given its location. No loading and unloading with ice and no tectonic activity and so no change in the stress regime. |
| Intrusive/extrusive processes | Non issue for Harwell given its location and lack of intrusive activity in the last 35 million years. |
| HUMAN ACTIVITIES | |
| Other human activities | It may be necessary to differentiate between upland and lowland land-uses and activities. Note that with cooling the upland essentially stays "grassland". The species mix will change but essentially remain grassland. The lowland will move from arable to pasture to grassland (again only relatively little change from boreal to tundra) – the primary productivity will change though.<br>Urban, industrial and agricultural land uses exist today. These land uses continue to exist – climate and other factors allowing. The possibility of having a more natural system (semi-natural) is not excluded at this stage.<br>It is assumed that the water discharge will be consistent with the biosphere system at the time of the release; which leads to no *a priori* exclusion of biosphere system type due to different land use. |

### C5.5.4. Identification of potential impacts on the biosphere system

The next step consists of developing a table showing the impact of the mechanisms of change, identified above, on each of the biosphere system components, identified previously. For each cell in Table C87, it was initially proposed that the following information was required for the Harwell site:

— the nature of the change;

— the temporal and spatial scales over which the change occurs; and

— the speed with which each biosphere system component responds to the change.

Note that for the purposes of Table C87, it was found helpful to aggregate the mechanisms of change identified into three categories: climate change; landform development processes; and societal change. Furthermore, as the process of identifying the nature of the change, the associated scales, and response times, progressed, it was recognised that consideration of the temporal and spatial scales was not necessary at this stage of system identification. Thus the nature of the change and the response time were only considered for some of the cells in Table C87.

TABLE C87. MECHANISMS OF CHANGE AND THEIR IMPACTS ON THE BIOSPHERE SYSTEM FOR THE HARWELL SITE (SEE MAIN TEXT FOR THE CONTENT OF EACH CELL)

| | Climate change | Landform development processes | Societal changes |
|---|---|---|---|
| Climate | 1.1 | 1.2 | 1.3 |
| Water bodies | 2.1 | 2.2 | 2.3 |
| Human activities | 3.1 | 3.2 | 3.3 |
| Biota | 4.1 | 4.2 | 4.3 |
| Near surface lithology | 5.1 | 5.2 | 5.3 |
| Topography | 6.1 | 6.2 | 6.3 |
| Geographical extent | 7.1 | 7.2 | 7.3 |
| Location | 8.1 | 8.2 | 8.3 |

1.1 Climate change on local climate:

— Nature of change: extremes are from Mediterranean conditions through to periglacial conditions (with warming as well as cooling).

— Spatial and temporal scales: Spatial scale: from the site itself and up to 200 km grid scale. Largest scale might be 10 km grid for water catchment. Temporal scale – 30 years to 1 million years (note that 30 is chosen on the basis of human lifetime).

— Speed of response: Not applicable.

1.2 Landform development processes on climate: Not relevant because landform changes are assumed to be small (see above) and so the impacts on climate are small. Climate drives the landform changes rather than vice versa.

1.3 Societal change on climate: Local societal changes affect local climate. Could have aerosol processes and heat dome effects and vegetation changes. But these changes will probably only be small – they will not change the climate class group. Global climate impacts due to global human activities are covered under 1.1.

2.1 Climate change on water bodies :

— Nature of change: Phase, turnover, volume, nature (frozen, unfrozen), groundwater-surface water connectivity and flow are all affected.

— Spatial and temporal scales: same as 1.1.

— Speed of response: of the order years for shallow surface water and near surface aquifer.

2.2 Landform development processes on water bodies:

— Nature of change: flow, discharge/recharge, frequency of over-banking.

— Spatial and temporal scales: spatial scales up to 10s of km (i.e. the water catchment area).

— Speed of response: of the order years for shallow surface water and near-surface aquifer.

2.3 Societal change on water bodies:

— Nature of change: creation/destruction of water bodies, changes in volume and turnover rate of existing water bodies (via reservoir construction, groundwater abstraction (Interfaces between geosphere and biosphere models are relevant here).

— Spatial and temporal scales: spatial scales from metres to 10s of km.

— Speed of response: of the order years.

3.1 Climate change on human activities:

— Nature of change: Nature of settlement (density, seasonal occupancy), habits.

— Spatial and temporal scales: Population might migrate into/out of the area.

— Speed of response: Order of years.

3.2 Landform development processes on human activities:

— Nature of change: No change, given the minor nature of the expected landform changes (see Table C86).

3.3 Societal change on human activities: not applicable.

4.1 Climate change on biota:

— Nature of change: Composition of ecosystem (biomass, production, type of species).

— Spatial and temporal scales: Not needed at present.

— Speed of response: Years to thousands of years.

4.2 Landform development processes on biota: No change in this case given the minor nature of the expected landform changes (see Table C86) (but note that if had significant change in landscape it might change the nature of the crops/pasture).

4.3 Societal change on biota:

— Nature of change: composition of wild and domestic fauna and flora and associated productivity.

— Spatial and temporal scales: not needed at present.

— Speed of response: order of years to 10s of years.

5.1 Climate change on near-surface lithology:

— Nature of change: composition, structure: - this might not be significant under boreal conditions, but could be more significant under tundra conditions.

— Spatial and temporal scales: Not needed at present.

— Speed of response: In the order of 1000s of years.

5.2 Landform development processes on near-surface lithology:

— Nature of change: Small change, some meandering.

— Spatial and temporal scales: not needed at present.

— Speed of response: 100s to 1000s of years.

5.3 Societal change on near-surface lithology:

— Nature of change: Soil management will cause changes in composition, structure, productivity.

— Spatial and temporal scales: not needed at present.

— Speed of response: years to 10s of years.

6.1 Climate change on topography:

— Nature of change: no major change for the Harwell site but there will be down cutting and some solutional erosion.

— Spatial and temporal scales: not needed at present.

— Speed of response: in the order of 5000 years.

6.2 Landform development processes on topography:

— Nature of change: small changes, incision by rivers.

— Spatial and temporal scales: not needed at present.

— Speed of response: 1000s to 10000s of years.

6.3 Societal change on topography: Note some excavation of minerals at present. But in this case the assessment context suggests that society responds to environmental change rather than driving. Concluded no change in this case due to the assessment context.

7.1 Climate change on geographical extent: no major change.

7.2 Landform development processes on geographical extent: no change.

7.3 Societal change on geographical extent: Note that for this example there is probably no change. (That there might be tendency for a more nomadic lifestyle but this does not have an impact on the geographical extent for this assessment context, because of the need to calculate individual dose rather than collective dose).

8.1 Climate change on location: no major change – the site will remain inland.

8.2 Landform development processes on location: no change – the site will remain inland.

8.3 Societal change on location: no change – the site will remain inland.

### C5.5.5. Infer alternative biosphere systems

Possible approaches to select the relevant biosphere systems were discussed during the Vienna meeting. The most straightforward approach identified starts by considering the types of biosphere systems associated with the main mechanism(s) of environmental change:

- identify major mechanism(s) of change for the site (e.g. climate change);
- identify possible alternatives for biosphere system components using the Level I tables of Annex BI of Part B.

Another approach consists of defining limits for future conditions at the site consistent with the main mechanism(s) causing environmental change (i.e. consider "maximum" and "minimum" conditions for "normal" human habitation). Then consider limits for each of the biosphere components within these maximum and minimum conditions.

- identify major mechanism(s) of change for the site (e.g. climate change);
- identify range of limits for the biosphere system (e.g. limits in climatic parameters);
- identify range of biosphere system components.

It was felt that the second approach introduces more arbitrariness than the first approach and it was therefore decided not to apply it for the Harwell sub-example. Instead, it was agreed to adopt the first approach.

In the case of the Harwell site the main mechanism causing biosphere system change is climate change. Therefore, it is necessary to identify the possible future climate states that might exist at the Harwell site. At this stage of system identification, it is sufficient to use the relatively coarse climatic classification of Table CI. However, when a more detailed biosphere description is required, more detailed approaches can be used. For example:

- palaeodata can be used to reconstruct past climatic conditions;
- current climate maps can be used to identify present day analogues; or
- modelling of future climate can be used.

Using Table CI to screen the climate states that may be relevant in the future, the following list was derived:

- ZBI : no, given the location of Harwell is fixed in northern Hemisphere;
- ZBII : no, ditto;
- ZB III : no, ditto;
- ZB IV : no, too dry in the summer given maritime location of the British Isles;
- ZB V : yes, due to global warning;
- ZB VI : yes, present day climate state;
- ZB VII : no, too continental;
- ZB VIII : yes, due to cooling;

— ZB IX : yes, due to a more intense cooling (tundra may exist, but not polar due to the absence of glacier covering the site.

Three climate states, different from the current one, were identified as relevant; the biosphere system components consistent with each climate state are identified in Table C88 using the Type I tables of Annex BI of Part B. It was not found useful to include the present temperate climate state in Table C88 since it has already been described in Step 1 (the review of the assessment context in Section C5.2).

Five possible biosphere systems can be derived from the information given in Table C88 and the previous sections:

— temperate,

— warm temperate,

— cooling boreal,

— warming boreal,

— tundra.

TABLE C88. IDENTIFICATION OF BIOSPHERE SYSTEMS UNDER DIFFERENT CLIMATE STATES FOR HARWELL SUB-EXAMPLE

| Climate states / Components | ZBV: warm temperate | ZBVIII: boreal | ZBIX: tundra |
|---|---|---|---|
| Geographical extent & topography | Inland, lowland, plain & subdued, limited erosion (but increased in comparison with present-day due to increased precipitation) | Inland, lowland, plain & subdued, some fluvial incision due to sea level fall, and limited erosion due to freeze-thaw processes | Inland, lowland, plain & subdued, some fluvial incision due to sea level fall, and limited erosion |
| Human activity | Large scale trading with low and high level of biosphere management (urban, industrial, commercial agriculture, mineral exploitation). Population density may reflect the nature of climate, fundamental human activities will remain essentially the same, but habits will change due to climate. | Large scale trading with low and high level of biosphere management (urban, industrial, commercial agriculture, mineral exploitation). If coming from cooler climate: Small scale trading (all three categories i.e. including market town) will allow cautious assumption of the production of locally produce foodstuffs. | Large scale trading (urban, industrial, zero-land farming, mineral exploitation); and none trading (nomadic/hunter gatherer, primitive agriculture). Small scale trading not considered because of poor production capacity of land. |
| Near surface lithostratigraphy | Sedimentary, less humus than at present, similar soils to those found at present? Maybe podzols | Sedimentary, possibly podzols | Sedimentary, Tundra humus soils with solifluction |
| Water bodies | Springs, streams, rivers, wells, reservoirs, water storage and distribution systems, aquifer | Springs, streams, rivers, wells, reservoirs, water storage and distribution systems, aquifer | Springs, streams, rivers, wetlands (due to poor drainage with seasonally frozen ground), wells, reservoirs, water storage and distribution systems, aquifer |
| Biota | Managed terrestrial systems (excluding rough grassland), man made reservoirs,<br>semi-natural aquatic ecosystem (rivers and streams) | Managed terrestrial systems (as present day but including rough grassland), man made reservoirs,<br>semi-natural aquatic ecosystem (rivers and streams)<br>If coming from cooler climate: All the above plus semi-natural system (lowland grass heath, neglected grassland) and natural (rivers, woodland and shrub land) | Managed terrestrial systems (grassland (all types), greenhouse, built up land, suburban, urban open space, hard cover, transport routes), reservoirs<br>semi-natural aquatic ecosystem (rivers and streams)<br>semi-natural terrestrial ecosystem (grassland and heath)<br>natural ecosystems (tundra meadow, swamp and marsh, rivers) |

### C5.5.6. Representation of biosphere system change

#### *C5.5.6.1. Choice of the sequential or non-sequential approach*

Two approaches can be used:

- *Non-sequential approach:* alternative (independent) biosphere systems are considered with their particular sequence and duration being disregarded. Each biosphere system is constant and represents an equilibrium state.
- *Sequential approach:* temporal change within any biosphere system and/or from one biosphere system to another is explicitly considered and represented through sequential discrete states or through continuous variation. Each biosphere system has a "memory" of the previous system and its components. The change and its associated impact might be sudden or gradual and might result from one or more mechanisms, such as climate change and/or human actions.

The choice of approach can depend on a number of factors.

- Assessment context – The assessment context states that one of the purposes of the assessment is to guide biosphere research priorities especially with respect to the performance of the system in response to biosphere system change. Given this purpose, it might be useful to undertake the assessment using both the non-sequential and sequential approach. This would allow the two approaches to be compared and contrasted.
- Technical and scientific resources available – capabilities have been developed to allow the use of both the non-sequential and sequential approach. Indeed, in the Dry Run 3 assessment of the Harwell site (Sumerling, 1992), the more resource intensive sequential approach was used. However, there were practical limitations to the resources available within the BIOMASS Theme 1 work programme and therefore the less resource intensive non-sequential approach might be more appropriate to use, at least initially.
- Importance of representing the order of the system change sequence – from above, it can be seen that the order of sequence can be important, at least for the boreal state. From Table C88, it can be seen that for the boreal state, it is necessary to distinguish between a warming and a cooling boreal. For the warming boreal the previous state was tundra, whilst for the cooling boreal it was temperate. Thus, it might be considered appropriate to use the sequential approach. However, the non-sequential approach could also be used so long as two boreal states were identified; a warming boreal and a cooling boreal.

From the above discussion, it can seen that there are good reasons for adopting either the non-sequential or sequential approach or maybe both. As a practical way forward within BIOMASS, it was decided to implement first the non-sequential approach, focusing on the tundra and the cooling and warming boreal systems, since ERB 2A and 2B focus on temperate systems. Then the sequential approach could be considered with special emphasis on the transition between boreal/tundra systems. This was considered to be a pragmatic way forward and has the benefits of: allowing comparisons to be made between the different biosphere systems; and, at least initially, avoiding the potentially resource intensive need to represent system change explicitly.

*C5.5.6.2. Selection of appropriate systems*

The following five non-sequential biosphere systems should be considered:

- temperate;
- warm temperate;
- cooling boreal;
- warming boreal; and
- tundra.

The biosphere system components for each of these systems need to be identified from information already collated in Table C88. For the temperate system, it was assumed future temperate systems are broadly similar to the present day temperate system identified. This assumption might not be valid for other sites and other assessment contexts. However, given that it is assumed that the site is unaffected by fundamental environmental change, such as that resulting from glaciation, and that society only responds to environmental change (see above), it was considered to be an appropriate assumption.

*Temperate*

*Climate and Atmosphere (Table CI):* The most appropriate class for Harwell is *ZB VI* (typical temperate with a short period of frost). Data in Sumerling et al., (1992) shows that currently there is a mild winter lasting three to four months during which frosts can occur. At present, average daily temperatures during the winter period rarely fall below freezing. The mean annual temperature is currently 9.5 °C and mean annual precipitation is currently 688.5 mm. It is assumed that any future temperate system has the same climate conditions.

*Geographical Extent and Topography (Table TI):* The site is assumed to have the following characteristics that are consistent with those found there today.

- Geographical context: *inland* – the site is located about 80 km from the sea.
- Altitude: *lowland* – the altitude in the region of the site ranges from less than 50 m in the Vale of the White Horse to around 250 m on the Berkshire Downs. It is assumed that there is no significant future erosion or deposition affecting the site.
- Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse with low relief. To the south are the Berkshire Downs and the Chilterns with rolling topography. It is assumed that limited future erosion/deposition ensures that the landform is similar to that found at present at the site.
- Localised erosion: *limited localised erosion* – no significant erosion under temperate conditions is assumed.

*Human Activity (Table HI):* Using data from Sumerling et al., (1992), the current type of human activity in the area of the site can be best described as a *large-scale trading community type* with a wide range of community types/activities and associated level of biosphere management. Examples of both low and high levels of biosphere management can be found. Much of the rural region around the site is used for agriculture and horticulture with the production of crops (especially cereals and fruit) and animals (especially cattle). In addition, there are several large towns (such as Didcot and Abingdon), and some mineral exploitation (e.g. sand and gravel) and industrial landuse (e.g. coal fired power station and the Harwell nuclear research facility). It is assumed that the same activities are found in future temperate conditions.

*Near-surface Lithostratigraphy (Tables GI, SI and RTI):* Details of the geology currently underlying and in the region of the site are given in Sumerling et al., (1992). Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as *sedimentary*. CEC (1985) classifies the soils in the area around the site using the FAO classification scheme. Common soil types are *Eutric Glesols, Orthic Luvisols, Chromic Luvisols and Orthic Rendzinas*. Only the Chromic Luvisols are explicitly mentioned in Table SI. It is assumed that this lithostratigraphy will be found in future temperate conditions.

*Water Bodies (Table WI):* As under present-day temperate conditions, i.e.:

- *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*.
- With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.
- *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI):* Table BI classifies terrestrial and aquatic ecosystems function of their level of management. It should be noted that fauna and flora classified under biota are first defined using the ecosystem classification, which is more general. The detailed list of the components of the biota will be provided in the description of the biosphere systems. The streams and rivers might be considered to be *natural ecosystems*, but even they are often influence by humans through the abstraction of water and discharge of sewage and other contaminants, so classification as *semi-natural aquatic ecosystems* might be more appropriate. Certainly, the reservoir is a *managed ecosystem*. The terrestrial system in the area of the site is essentially a *managed ecosystem*. In light of information given in Sumerling et al., (1992), all the managed terrestrial ecosystems listed in Table BI can be included with the exception of rough grassland. It is assumed that these conditions occur under future temperate conditions.

*Warm temperate*

*Climate and Atmosphere (Table CI): ZB V* (warm temperate, maritime, humid). Assume rainfall occurs principally in winter and no summer-drought season.

*Geographical Extent and Topography (Table TI):* The site is assumed to have the following characteristics that are broadly consistent with those found there today.

- Geographical context: *inland* – the site is located about 80 km from the sea.
- Altitude: *lowland* – the altitude in the region of the site ranges from less than 50 m in the Vale of the White Horse to around 250 m on the Berkshire Downs. It is assumed that there is no significant future erosion or deposition affecting the site (see below).

— Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse with low relief. To the south are the Berkshire Downs and the Chilterns with rolling topography. It is assumed that limited future erosion/deposition (see below) ensures that the landform is similar to that found at present at the site.

— Localised erosion: *limited localised erosion* – but increased in comparison with the present-day due to increased precipitation (see Table C88).

*Human Activity (Table HI): Large scale trading* with low and high level of biosphere management (urban, industrial, commercial agriculture, mineral exploitation). Although the population density may reflect the nature of climate, the fundamental human activities are assumed to be essentially the same as present-day temperate, although habits are assumed to be modified due to the warming of climate.

*Near-surface Lithostratigraphy (Tables GI, SI and RTI):* Assumed to be essentially the same as at present-day. Details of the geology currently underlying and in the region of the site are given in Sumerling et al., (1992). Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as *sedimentary*. Common soil types are *Eutric Glesols, Orthic Luvisols, Chromic Luvisols and Orthic Rendzinas*. Possibility of podzols forming.

*Water Bodies (Table WI):* As under present-day temperate conditions, i.e.:

— *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*.

— With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.

— *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI):* All *managed terrestrial ecosystems* (excluding rough grassland), *man made reservoirs, semi-natural aquatic ecosystem (rivers and streams)* (see Table C88).

*Cooling boreal*

*Climate and Atmosphere (Table CI): ZB VIII* (boreal). Assume that the duration of the period with a daily average temperature of more than 10º C drops below 120 days and the cold season lasts longer than 6 months. The northern boundary between the boreal zone and the arctic tundra is where only approximately 30 days with a daily mean temperature above 10º C and a cold season of 8 months are typical of the climate. Assume a cold oceanic climate with a relatively small temperature amplitude.

*Geographical Extent and Topography (Table TI):* The site is assumed to have the following characteristics that are broadly consistent with those found there today.

— Geographical context: *inland* – the site will be more inland than at present due to the expected fall in sea level under boreal conditions.

- Altitude: *lowland* – the altitude in the region of the site ranges from less than 50 m in the Vale of the White Horse to around 250 m on the Berkshire Downs. It is assumed that there is no significant future erosion or deposition affecting the site (see below). Note that the expected fall in sea level under boreal conditions might result in a slight increase in altitude relative to the sea level.
- Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse with low relief. To the south are the Berkshire Downs and the Chilterns with rolling topography. It is assumed that limited future erosion/deposition (see below) ensures that the landform is generally similar to that found at present at the site.
- Localised erosion: *limited localised erosion* – but some fluvial incision due to sea level fall and some erosion due to freeze-thaw processes (see Table C88).

*Human Activity (Table HI): Large scale trading* with low and high level of biosphere management (urban, industrial, commercial agriculture, mineral exploitation).

*Near-surface Lithostratigraphy (Tables GI, SI and RTI):* Assumed to be essentially the same as at present-day. Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as sedimentary. Common soil types are *Eutric Glesols, Orthic Luvisols, Chromic Luvisols and Orthic Rendzinas*. Possibility of podzols forming.

*Water Bodies (Table WI):* As under present-day temperate conditions, i.e.:

- *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*.
- With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.
- *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI): All managed terrestrial ecosystems* (excluding rough grassland), *man made reservoirs, semi-natural aquatic ecosystem (rivers and streams)* (see Table C88).

*Warming boreal*

*Climate and Atmosphere (Table CI): ZB VIII* (boreal). Assume that the duration of the period with a daily average temperature of more than 10º C drops below 120 days and the cold season lasts longer than 6 months. The northern boundary between the boreal zone and the arctic tundra is where only approximately 30 days with a daily mean temperature above 10º C and a cold season of 8 months are typical of the climate. Assume a cold oceanic climate with a relatively small temperature amplitude.

*Geographical Extent and Topography (Table TI):* The site is assumed to have the following characteristics that are broadly consistent with those found there today.

- Geographical context: *inland* – the site will be more inland than at present due to the expected fall in sea level under boreal conditions.

— Altitude: *lowland* – the altitude in the region of the site ranges from less than 50 m in the Vale of the White Horse to around 250 m on the Berkshire Downs. It is assumed that there is no significant future erosion or deposition affecting the site (see below). Note that the expected fall in sea level under boreal conditions might result in a slight increase in altitude relative to the sea level.

— Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse with low relief. To the south are the Berkshire Downs and the Chilterns with rolling topography. It is assumed that limited future erosion/deposition (see below) ensures that the landform is generally similar to that found at present at the site.

— Localised erosion: *limited localised erosion* – but some fluvial incision due to sea level fall and some erosion due to freeze-thaw processes (see Table C88).

*Human Activity (Table HI): Large scale trading* with low and high level of biosphere management (urban, industrial, commercial agriculture, mineral exploitation). Also possibility under warming boreal conditions of *small scale trading* (all three categories i.e. including market town) (see Table C88).

*Near-surface Lithostratigraphy (Tables GI, SI and RTI):* Assumed to be essentially the same as at present-day. Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as *sedimentary*. Common soil types are *Eutric Glesols, Orthic Luvisols, Chromic Luvisols and Orthic Rendzinas*. Possibility of podzols forming.

*Water Bodies (Table WI):* As under present-day temperate conditions, i.e.:

— *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*.

— With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.

— *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI):* All *managed terrestrial ecosystems* (excluding rough grassland), *man made reservoirs, semi-natural aquatic ecosystem (rivers and streams)* (see Table C88). Also possibility under warming boreal conditions of semi-natural system (lowland grass heath, neglected grassland) and natural (rivers, woodland and shrub land).

*Tundra*

*Climate and Atmosphere (Table CI): ZB IX* (arctic). Assume that at most, there are 188 days in the year with mean temperature above 0º C, and sometimes as few as 55. The low summer temperatures are partially due to the large amount of heat required to melt the snow and thaw out the ground. Winters are rather mild due to oceanic effects. Precipitation is slight, often being less than 200 mm, but since potential evaporation is also very low, the climate is humid. Surplus water is unable to seep into the ground because of permafrost and thus extensive swamps are formed. Snowfall amounts to 19-50 cm annually.

*Geographical Extent and Topography (Table TI):* The site is assumed to have the following characteristics that are broadly consistent with those found there today.

— Geographical context: *inland* –the site will be more inland than at present due to the expected fall in sea level under tundra conditions.
— Altitude: *lowland* – the altitude in the region of the site ranges from less than 50 m in the Vale of the White Horse to around 250 m on the Berkshire Downs. It is assumed that there is no significant future erosion or deposition affecting the site (see below). Note that the expected fall in sea level under tundra conditions will result in a slight increase in altitude relative to the sea level.
— Landform: *plain and subdued* – to the north of the site is the Vale of the White Horse with low relief. To the south are the Berkshire Downs and the Chilterns with rolling topography. It is assumed that limited future erosion/deposition (see below) ensures that the landform is generally similar to that found at present at the site.
— Localised erosion: *limited localised erosion* – but some fluvial incision due to sea level fall (see Table C88).

*Human Activity (Table HI): Large scale trading* with high level of biosphere management (urban, industrial, zero-land farming, mineral exploitation), and none trading (nomadic/hunter gatherer, primitive agriculture). Small scale trading not considered because of poor production capacity of land.

*Near-surface Lithostratigraphy (Tables GI, SI and RTI):* Assume that Pleistocene and recent drift deposits cover a large proportion of the area. Below the drift deposits are interlayered sandstones, limestones and mudstones of Mesozoic era. Thus the rock type can be categorised as *sedimentary*. Due to tundra conditions, it is assumed that *tundra humus soils* are found that are affected by solifluction.

*Water Bodies (Table WI):* As under present-day temperate conditions but with some modifications, i.e.:

— *Natural surface water bodies* are common in the area of the site. *Springs* feed *streams* that in turn feed *rivers*. Due to poor drainage with seasonally frozen ground, *wetlands* form.
— With regard to *artificial surface water bodies*, there are many water supply *wells (boreholes)* sunk into the chalk aquifer. There are *water storage and distribution systems*, as well as a *reservoir* to the north of the site.
— *Sub surface water bodies* are important, specifically the chalk *aquifer* which acts as a source of domestic, industrial and agricultural water.

*Biota (Table BI): Managed terrestrial ecosystems* (grassland (all types), greenhouse, built-up land, suburban, urban open space, hard cover, transport routes), *reservoirs, semi-natural aquatic ecosystem* (rivers and streams), *semi-natural terrestrial ecosystem* (grassland and heath), *natural ecosystems* (tundra meadow, swamp and marsh, rivers) (see Table C88).

C5.6. GENERIC SITE SUB-EXAMPLE BASED ON ERB2A

### C5.6.1. Review of assessment context

The system identified for the initial stage within this context, corresponds to the one identified and described in ERB 2A, the main components and characteristics of where are summarised below:

— The initial biosphere system corresponds to a present day agricultural community. A small farming community living off local produce (agricultural land use with production of animal products and crops for human and animal consumption). The primary route of contamination of the biosphere system is via the use of well water. The climate class (see Section C3.2), corresponds to a "temperate" with a high requirement for irrigation (ZBVII). The geographical context is specified as inland[16] and the region exploited by the local community is topographically identified as lowland, more likely to have a regional aquifer at accessible depth, and plain, consistent with the use of irrigation water for agricultural purposes, with limited localised erosion, consistent with the choice of the land for agricultural purposes and the absence of significant surface water courses. The underlying rock type is a sedimentary rock. The predominant soil type, chernozem**,** is consistent with the assumed climate (Table RTI) and geographical context. Natural surface water bodies were excluded from the context to avoid unnecessary complexity in development of the biosphere system description; indeed, it will be generally more cautious to assume that all water resources are derived from the well, rather than from local surface waters. (The description of the initial state for the present Example will also start from the same assumption). The biota component consists of managed and improved grasslands, field crops/cultivated land, and tree crops (non-commercial).

Considerations with respect to ERB2A Assessment Context.

— "Effective dose" is the end-point to be assessed and, "society" will change as necessary to accommodate biosphere system change so that it is consistent with societies found in present day analogue sites. This suggests an "*a posteriori*" description of the population group/s from the point of view of determining exposure, and the use of present analogue societies to determine the relevant habits etc.

— Radionuclide transport media in the geosphere may be relevant as long as the effects of change can affect the transport velocity and the dilution of the different radionuclides considered. In principle it is assumed that the main medium for radionuclide transport is groundwater. Contaminated groundwater comes from underneath the biosphere mixing with meteoric water at the subsurface level. The source term is assumed to be constant at a rate for each radionuclide entering the biosphere by whatever means.

— A subdued morphology was selected to explore the effects of landform evolution arising from changes occurring beyond the boundaries of the site of interest.

[16] Coastal geographical contexts are explored in the Äspö example case.

### C5.6.2. Identification of mechanisms of biosphere system change

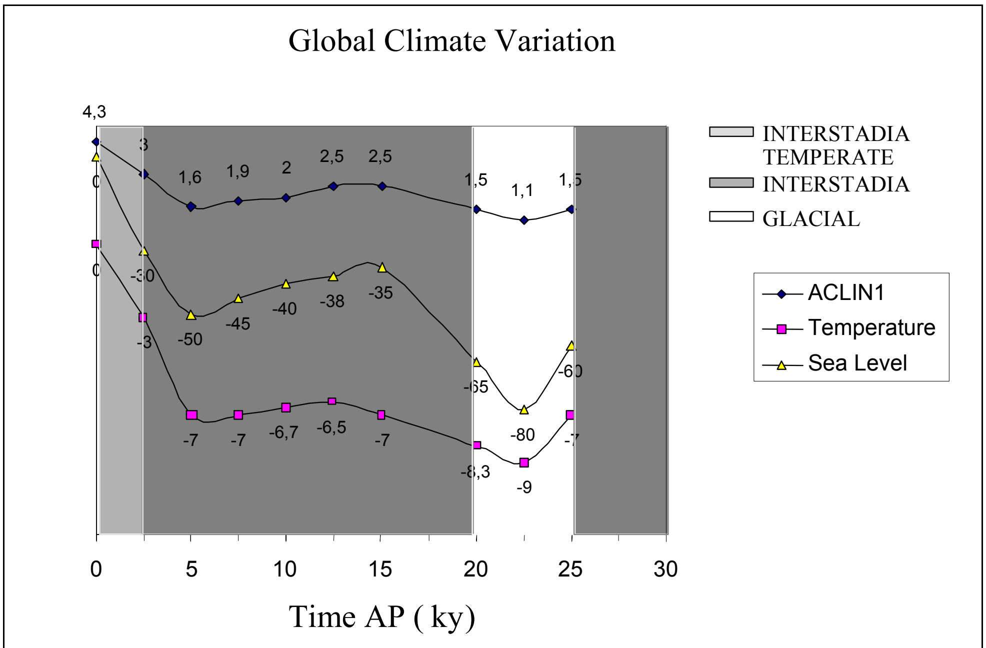
The biosphere system described above is the starting state of the system, for which the effects of the System Environment are analysed.

- "Large seismic events" and "Vulcanism" should be treated as single and instantaneous events with a probability of occurrence derived from the susceptibility of the area where the repository is planned to be sited, taking into account that the effects on the barrier system can be great, altering the main pathways of ground water to the surface or bringing radioactive material from the repository to the surface.
- "Meteorite impact" treatment is similar in concept to the above, although for this case the probability of occurrence can be more difficult to estimate. Again, the impact can affect dramatically the system resulting in a new and different state to be analysed.
- "Human influence on global climate" will be considered as part of the "Global Climate Change" (see later).
- "Isostacy", for an inland site, may affect the local system through variation in water erosion rates and water flow regimes/pathways due to the variation of the altitude, modifying the relative distance from the sea. The effect of "isostacy" in the local system is similar or equivalent to the effect of the sea level change due to "global climate change". For a specific site both processes should be analysed jointly to see the final combined effect. For this case, the effect of change in relative sea level is analysed within "global climate change".
- "Social/institutional developments", in the assessment context is assumed an '*a posteriori*' hypothesis: "*Society will change as necessary to accommodate biosphere system change so that it is consistent with societies found in present day analogue sites*". No changes are considered in the local system as a consequence of society actions or developments.
- "Global climate change" is the single high-level independent external FEP for which effects on the local biosphere system need to be analysed.

### C5.6.3. Identification of potential impacts on the biosphere system

The next item is to define attributes/characteristics for the 'initiators' previously selected. To estimate the effects of climate change for a hypothetical case, a glacial-interglacial cycle occurring during 30000 years is proposed in Figure C28 as an illustrative example to be explored.

ACLIN1 astronomic index moves from a temperate interstadial (initial state: ERB2A) to colder conditions, interstadial and then periglacial and glacial, with a subsequent temperature and sea level recuperation in an interstadial period.




Temperature (ºC) and Sea Level (m) in relative values with respect to the present day, given as Time "0".

*FIG. C28. Variation of the ACLIN1 climatic index between 0 and 30000y AP. Extrapolation of the sea levels and temperatures from the astronomic curve ACLIN1 (Goodess,* et al., *1992).*

Propagating these climate changes through the external environment model, "continental ice sheet" and "regional climate" will be directly affected with an indirect influence over the "regional ice sheets" and "regional hydrology". "Regional hydrology" will be modified as a result of the combination of the sea level variation, the regional ground water system and the regional climate.

The global climate change, as proposed in Figure C28 for this example, can be described by the following sequence:

— (0–2500 y) the annual average temperature decreases, from the assumed 2A conditions[17], at a rate of approximately 1º C every 1000 years. Global sea level drops at a rate of 10 m every 1000 years.

— (2500–5000 y) an interstadial period starts and remains for 17500 years. During the period specified, temperature and sea level decrease at a rate of approximately 2º C and 10 m every 1000 years respectively.

— (5000–15000 y) average annual temperature is maintained low and more or less stable during this period. Water sea level increases slowly from –50 m to –35 m at the end of this period.

[17] Initial conditions for temperature correspond to ERB2A conditions and global sea level is assumed to be as at present. Both initial temperature and global sea level are represented in Figure 28 by "0" reference. The initial annual average temperature ranges from 5 to 8ºC.

— (15000–20000 y) a new cooling period starts moving towards lowers temperature and global sea level. At the end of this period, relative temperature is reduced by 1º C and, relative sea level drops 30 m.

— (20000–to 25000 y) the cooling process proceeds, starting a glacial period that persists for 5000 years. During the first 2500 years temperature and sea level decrease by 1º C and 15 m respectively, increasing during the second 2500 years by 2º C and 20 m respectively.

— (25000–30000 y) interstadial conditions are reached again.

The response of the regional landscape to these global changes can be different depending on the latitude, altitude and distance to the sea of the area of interest. The initial inland site will become more inland as *sea level* goes down. Seasonal changes would normally become more acute, with the *regional climate* directly influenced by global climate. Continental ice sheet develops from the north to the south in the northern hemisphere, invading more area as temperature decreases; the *regional ice sheet* may or may not reach the area of interest. *Glacier* development depends on altitude and temperature and develops from higher points to lower areas. The initial landform is subdued with an altitude and relief consistent with agricultural activities and the existence of a sedimentary aquifer at accessible depth.

Although glaciers can influence surrounding areas, glacier development is excluded for the subdued, lowland area selected. Compensation of isostasy effects and sea level drop over the hydrostatic level are, therefore ignored. *Regional vegetation and soils* accommodate to regional climate regime, which moves towards colder conditions, from temperate to cold-temperate (boreal) and then, polar. *Regional hydrology* is a function of all the regional variables mentioned above and different situations are possible. Global sea level drop increases the surface flow gradients producing incision into the subdued morphology, narrower riverbeds and quicker flows, with higher erosion rates. Water table levels (WTL) for the regional catchment generally drop as a consequence of the new hydrology system (annual average rainfall and snowfall variations need to be considered in the water balance). Permafrost conditions can appear over the area with consequences for the water balance. Water movement at the surface can be reduced due to a low infiltration rate and no or low flow at the bottom of the water surface bodies. Water table level will generally drop due to reduction of surface water recharge and sea level drop. Volumetric flow in subsurface aquifers can decrease to a degree, preventing exploitation of groundwater.

Bearing in mind the previous general discussion, each selected timeframe is analysed below, to define the boundary conditions of the local biosphere system. Special attention is given to the geo-biosphere interface, assuming a constant release rate from the geosphere[18].

— (0–2500 y): at the end of the period, the annual average temperature has decreased 3º C and global sea level has dropped by 30 m from present level.

  - Continentality increases for inland sites, due to the sea level drop, and climate characteristics vary to reach annual averages temperature between 2ºC to 5ºC, rainfall between 300 to 400 mm and, potential evaporation between 600 to 800 mm (Walter, 1984). Although climate characteristics at the end of this period are modified, climate type remains within the ZBVII class, as in the initial biosphere

[18] Changes at a global scale will also affect geosphere processes but are not considered here. It could be appropriate to ensure consistent treatment throughout the overall performance assessment .

system. Changes in climate conditions: more rainfall and less evaporation, imply more availability of water resources within the system.

- The source term is not assumed to be modified and, the geo-biosphere interface through the aquifer can vary, increasing the available volume of groundwater, with an elevation in the water table level (WTL). (Another possibility would be to consider an increase in groundwater flow, always limited by the transmisivity of the medium, with no or small elevation of the water table level, by the effect of compensation of WTL rise with the sea level drop. This hypothesis will imply more dilution of the radionuclides in the aquifer). Conservatively, if the same degree of dilution is considered in the aquifer, as in ERB2A, and the water table rises, a reasonable change in the system will be to consider direct releases of groundwater to land or water bodies, where there were no previous groundwater releases.
- Conservatively, the same local area can be assumed for both sequential sources of contamination: from a well (ERB2A), first and, from a natural groundwater release (ERB2B), afterwards. The change from one biosphere system (ERB2A) to the other (ERB2B) can be made by considering an initial radionuclide concentration, in the main components of the ERB2B system (soils/sediments), equal to the radionuclide concentration at equilibrium derived for ERB2A.

— (2500–5000 y) the cooling period proceeds starting an interstadial phase. Temperature and sea level decrease at a rate of approximately 2º C and 10 m every 1000 years, respectively.

- Continentality increases and climate characteristics reach annual averages temperature between -2º C to 1º C, rainfall between 400 to 450 mm and, potential evaporation between 400 to 550mm (Walter, 1984)[19]. Climate characteristics, at the end of this period, correspond to a cold-temperate climate (Boreal), ZBVIII class from Walter (1984) (see Figure C29). The main changes are: more rainfall (snowfall) and, less evaporation, implying more water within the system during the third part of the year; the temperature is above 10º C (growing season) and surface waters are not frozen.
- The geo-biosphere interface (the aquifer) increases in annual average volumetric flow due to higher water availability into the system[20]. Nevertheless, account should be taken of seasonal variation in infiltration rates, from colder to warmer months that can vary greatly the water table levels. Annual average values will result, generically, in a higher dilution of radionuclides within the aquifer.
- New radionuclide equilibrium state/s will be reach in the biosphere system during this period. However, if the source term flux is maintained, corresponding radionuclide concentration values could be lower than in the previous period.

[19] Climate data obtained from Walter (1984) for this period do not account for the influence, at a global scale, of the sea level drop, which will imply, also at a global scale, a lower hydrostatic level. This, in turn, can compensate the effect of WTL rise due to the higher availability of water assumed for the biosphere system in this period.

[20] This implies a variation in the source term to the biosphere and a need for a consistency of assumptions for change made in the geosphere part of the assessment.

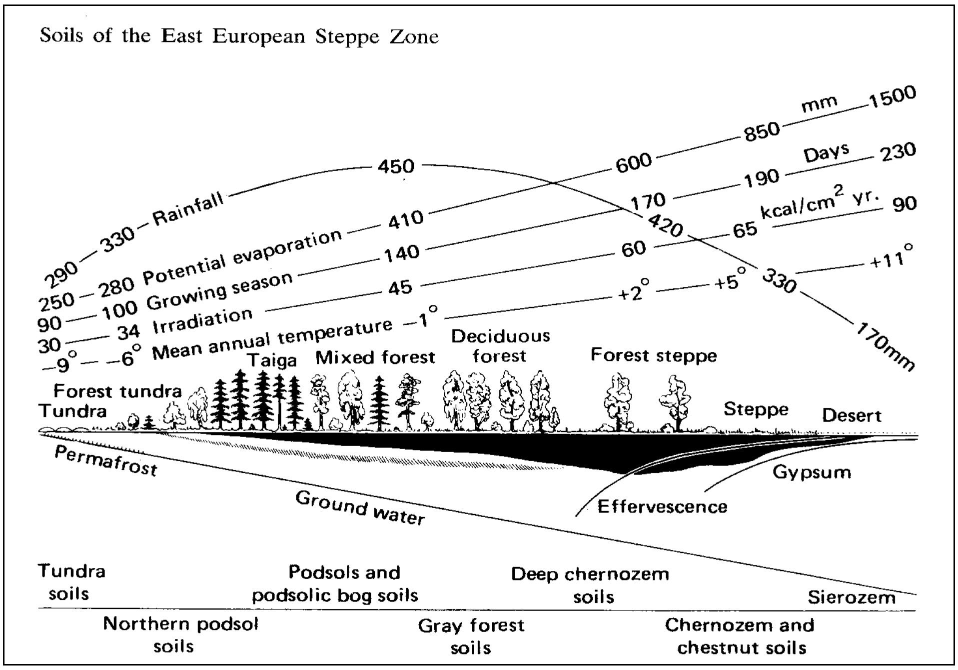



*FIG. C29. Schematic climate, vegetation, and soil profile of the east European lowlands from northwest to southeast (Walter, 1984).*

— (5000–15000 y) average annual temperature is maintained low and more or less stable during this period. Sea level increases from –50 m to –35 m by the end of this period.

- Climate characteristics corresponding to a cold-temperate climate (Boreal), ZBVIII class are maintained, with a smooth but constant rise in the hydrostatic level up to –35 m with respect to the initial sea level considered.
- As in the previous period, the geo-biosphere interface (the aquifer) increases the annual average volumetric flow due to higher water availability into the system. However, account should be taken of seasonal variation in infiltration rates, from colder to warmer months that can result in large variations in the water table levels. Annual average values will result in a higher dilution of radionuclides in the aquifer. Elevation of the global sea level, maintaining temperature conditions, will decrease the gradient of the surface water currents, with a re-accommodation of the WTL to a new situation. This will imply, in general, greater volumetric flow in the aquifer resulting in radionuclide dilution.
- New radionuclide equilibrium state/s will be reached in the biosphere system during this period. However, if the source term is maintained, the corresponding radionuclide concentration values will be smaller than in the previous period. No special accumulation processes can be thought of in the interface, so no special radiological consideration should be given to this period, when the source term to the biosphere is maintained constant.

— (15000 years to 20000 years) a new cooling period starts moving towards lower temperature and global sea level. At the end of this period, relative annual average temperature is reduced by 1° C and, relative sea level drops 30 m.

- Climate characteristics get colder towards periglacial conditions. A transition from the boreal mixed forest to the coniferous forest is produced in natural climax conditions. Global sea level decreases quickly during this period, moving the hydrostatic level down another 30 m.

- Annual average temperatures move to colder conditions to between -3º C and 0º C, at the end of this period. Annual average precipitation ranges from 380 to 450 mm and, potential evaporation ranges from 350 to 450 mm (data refer to present ecosystems that do not account for the influence of sea level drop).
- In these conditions, dismissing the sea level effect, annual water balance of the system does not change very much since the climate characteristics do not allow for permafrost conditions. Accounting for sea level drop, changes in the WTL can be assumed according with the decrease in the hydrostatic level. The annual average volumetric flow in the aquifer can be reduced, decreasing the dilution capacity, which in turn will increase radionuclide concentration in the aquifer.
- A detailed analysis of the interface processes should be performed, although generically, the following considerations can be made: (a) If the exploitation capacity and groundwater flux in the aquifer are maintained, radionuclide concentration in the aquifer will be increased by a factor proportional to the WTL change ($C(Bq/m^3) = C_0 \times WTL_0 / WTL$). Groundwater release points to the surface will result lower base levels and direct release to land surface will be less possible, apart from wells. (b) If the reduction in the aquifer volumetric flow prevents the exploitation capacity but the groundwater flux is maintained, releases to surface water bodies should be considered, with the corresponding increase in the radionuclide concentrations in groundwater.
- New radionuclide equilibrium state/s will be reach in the biosphere system during this period. Dose conversion factors have to be re-evaluated for a boreal climate and new aquifer conditions.

— (20000 years to 25000 years) the cooling period proceeds, starting a glacial period that remains for 5000 years. During the first 2500 years, temperature and sea level decrease by 1º C and 15 m respectively, increasing during the second 2500 years by 2º C and 20 m respectively.

- Climate characteristics get colder towards glacial conditions. A transition from boreal (ZBVIII) to tundra (ZBIX) states is produced in natural climax conditions. Global sea level drops another 15 m in 2500 years, going up during the next 2500 years by 20 m.
- Annual average temperatures move, first, to colder conditions to be between -4º C and -1º C, and then –2º C and 1º C, by the end of this period.
- The decrease in the hydrostatic level jointly with the decrease in temperatures can modify greatly the hydrological system. WTL and volumetric flow in the aquifer can be reduced dramatically, as well as surface water flows. Transport of radionuclides at the geo-biosphere interface is more complex as physico-chemical processes (e.g. salinity, diffusion) can be very significant.
- Groundwater flow, if any, can have a concentration of radionuclides limited by the solubility capacity of that water. Groundwater resources from the aquifer are not available due to both the low volumetric flow and the high water salinity. Life conditions are possible but unlikely since water needs would be provided by resources other than the subsurface aquifer.

- Modelling during this period can be focussed on the possibility of accumulation of radionuclides in the sedimentary geology, where the aquifer was located, restricting the need for dose calculations. The geosphere model should provide detailed information of radionuclide concentrations and fluxes reaching the interface.
- Under the assumed geosphere source term, 1Bq/y of each radionuclide constant with time, some general considerations can be made. The activity coming from the geosphere reaches the lower saturated zone. Part of it moves with the remaining ground water flow, and the other part is assumed to move upwards to the non-saturated zone. In the saturated zone, the activity of radionuclides is assumed to be in a steady state (variation of activity ($A_s$) as a function of time is null) given by the expression:

$$A_s = S_g / (\lambda_s + \lambda_r + \lambda_{ns})$$

where:

$S_g$ is the source term (1Bq/y);
$\lambda_s$ is the release rate from the saturated area considered ($y^{-1}$);
$\lambda_r$ is the disintegration constant ($y^{-1}$);
$\lambda_{ns}$ is the release rate to the non-saturated area considered ($y^{-1}$).

In the non-saturated zone, the variation of activity ($A_{ns}$) as a function of time will be given by the expression:

$$\delta A_{ns}/\delta t = \lambda_{ns} A_s - \lambda_r A_{ns} - \lambda_d A_{ns}$$

where:

$\lambda_d$ is the loss rate from the non-saturated area due to diffusion/dispersion processes.

— (25000 years to 30000 years) interstadial conditions are reached again.
    - Climate characteristics become warmer with a probable global sea level recovery. If conditions allow for an increase in the WTL, the saturated zone will increase, reaching the previously non-saturated medium, where radionuclide concentrations could have a non-zero initial value.
    - A transient of radionuclides release can occur, the magnitude and duration of which can be analysed as a function of the rate of increase in the WTL and the corresponding groundwater volumetric flow.

The previous discussion indicates that the following approach can be taken to modelling the effects of climate change on the biosphere and on radiological consequences:

— (0 years–2500 years) ➨ A sequential discrete approach with two cases: ERB2A first and ERB2B, afterwards, modifying the initial radionuclide concentrations from null values to equilibrium concentrations in ERB2A.

— (2500 years–5000 years), (5000 years – 15000 years) and (15000 years to 20000 years) ➨ A discrete Boreal system can be used as representative of this period, although more dilution, and then lower radionuclide concentrations, in the aquifer can be expected. Of special interest could be to explore the effects of seasonality and water table variations.

— (20000 years–25000 years) ➨ Reduced radiological consequences to man can be expected, due to the biosphere extreme conditions, although possible accumulation processes in the sedimentary geology should be explored (Geosphere models to consider groundwater variations). The concentration of radionuclides in the equilibrium state during this period should be used as initial conditions for the next period.

— (25000 years–30000 years) The dose consequences of a transient peak of radionuclide release should be considered if accumulation has previously taken place.

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## ANNEX CI
## AREAS OF LAND IN THE ERB 2A SYSTEM

It can be useful to consider the area under each crop type not only to help to characterise the physical model, but also to help development of consistent assumptions across the whole model. For example, cultivated areas imply the overall irrigation requirement. Some estimate of the total productivity of the ERB2A system can also be provided to show this is consistent with exposure group assumptions.

Table CI–1 shows how the areas of land can be estimated. The basic assumption is that the areas of land match diet preferences of the general population – the amount of production is in direct proportion to the consumption. The area devoted to each crop type is therefore given by the area required for each median consumer.

The yield of crops is taken mainly from BIOMOVS II (1996) with details of fruit from Smith et al., (1996). The yield of meat is somewhat more complicated since it depends on the live weight of animals, the edible fraction of the carcass and the stocking density of livestock. The Methodology is applicable to other types of livestock provided that corresponding data can be found.

TABLE CI–1. ESTIMATION OF CULTIVATED AREAS IN ERB2A

| Produce | Yield kg $m^{-2}$ | Comment | Median cons. rate kg $a^{-1}$ | *Critical* cons. rate kg $a^{-1}$ | Comment | Area per median consumer $m^2$ $a^{-1}$ | Fractional area – | Cultivated area $m^2$ | Approx. population median consumers |
|---|---|---|---|---|---|---|---|---|---|
| Meat | $5.00\times10^{-2}$ | Calculated | 41 | 120 | Median values – all meat, poultry & game! | $8.70\times10^{2}$ | $7.78\times10^{-1}$ | $6.98\times10^{6}$ | $8.02\times10^{3}$ |
| Milk | 1.2 | Calculated | 85 | 210 | Robinson (1996) – (IAEA (1982) ⇒ 180) | $7.08\times10^{1}$ | $6.34\times10^{-2}$ | $5.68\times10^{5}$ | $8.02\times10^{3}$ |
| Fruit | 0.7 | Smith et al., (1996) | 15 | 60 | Robinson (1996) | $2.14\times10^{1}$ | $1.92\times10^{-2}$ | $1.72\times10^{5}$ | $8.02\times10^{3}$ |
| Root veg. | 3.5 | BIOMOVS II (1996) | 55 | 110 | Robinson (1996) – (IAEA (1982) ⇒ 142) | $1.57\times10^{1}$ | $1.41\times10^{-2}$ | $1.26\times10^{5}$ | $8.02\times10^{3}$ |
| Green veg. | 2 | BIOMOVS II (1996) | 30 | 70 | Robinson (1996) – (IAEA (1982) ⇒ 120) | $1.50\times10^{1}$ | $1.34\times10^{-2}$ | $1.20\times10^{5}$ | $8.02\times10^{3}$ |
| Cereals | 0.4 | BIOMOVS II (1996) | 50 | 90 | Robinson (1996) – (IAEA (1982) ⇒ 142) | $1.25\times10^{2}$ | $1.12\times10^{-1}$ | $1.00\times10^{6}$ | $8.02\times10^{3}$ |
| | | | | | Totals | $1.07\times10^{3}$ | 1.00 | $8.97\times10^{6}$ | |

| Parameter | Value | Units | Comments |
|---|---|---|---|
| Stocking density of cattle | $2.00\times10^{-4}$ | animals $m^{-2}$ | BIOMOVS II (1996) - higher is calorific content of pasture is used. |
| Cattle carcass edible weight | 250 | kg $carcass^{-1}$ $a^{-1}$ | Schw. Bauen Sek. (1992). |
| Milk | 640 | kg $animal^{-1}$ $a^{-1}$ | Kane 1999. |
| Total modelled area | $1.00\times10^{7}$ | $m^2$ | Word picture. |
| *Area of farm yard & buildings* | $1.00\times10^{4}$ | $m^2$ | Assumed. |
| *Village area* | $1.00\times10^{6}$ | $m^2$ | Assumed. |
| *Number of farms* | 3 | - | From definition of types of exposure group. |
| *Cultivated area* | $8.97\times10^{6}$ | $m^2$ | Derived. |

The stocking density of cattle is as used in BIOMOVS II (1996) although a higher value may be calculated if all of the available crop is consumed, based on a model of the nutritional requirements of cattle. The yield of milk is also provided by this source and the yield of meat from beef cattle is given by data from current farming practices in Switzerland (SBS, 1992). It is assumed that offal is included in the edible fraction of beef cattle slaughtered for general meat products. Agricultural production is based on some other minor assumptions:

— Total area of ERB2A biosphere = 10 $km^2$ ($10^7$ $m^2$) from the word-picture;

— Area of village assumed to be 1 $km^2$ ($10^6$ $m^2$);

— Area of farm yard and buildings is $10^4$ $m^2$ for each of the farms.

This gives a total cultivated area of $8.97\times10^6$ $m^2$.

On this basis meat production would occupy the highest area, at over 75% of the total. The population supportable by the area would be around 8000 median consumers. This is well in excess of the 300 to 1000 inhabitants envisaged in the word-picture and agricultural exports from the modelled region may be inferred.

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# ANNEX CII
# DATA SELECTION FOR BIOMASS EXAMPLE REFERENCE BIOSPHERE 2A: AGRICULTURAL WELL

In determining appropriate judgements on parameter values consideration was given to:

- the assessment context;
- the biosphere system identification and justification;
- the biosphere system description;
- the exposure group definition;
- the model development;
- the mathematical model; and
- parameter lists for the mathematical model.

In applying the protocol to Example 2A, it was found that the data selection exercise is closely linked to the detail of the mathematical model. In the event, examination of the data resulted in interesting but, in the broad context of an overall PA, minor modifications to the model. Some alternatives were considered and dose implications explored, as set out in Annex CIII.

The ERB2A assessment context says use an equitable approach except for critical group assumptions, discussed previously, i.e. occupancy and consumption etc (Section C3.5.4 of main text), for which cautious assumptions are required.

## CI–1. APPLICATION OF THE PROTOCOL

Step 1 was done for the model as a whole including: taking assessment context, listing data requirements, listing parameters and compiling available information.

### CI–1.1. ELEMENT INDEPENDENT PARAMETER LIST

*Irrigation rate***,** m/y, in ZBVII. Value to be based on replacement of soil moisture deficit for sub-biome 3, arid but with some summer rain. Since it is dry, but there is open pasture and milk production, there has to be irrigation of pasture.

See p273 of Shaw (Thornthwaites formula), mean monthly rainfall and temperature, assume irrigating to field capacity, compute integral deficit and assume difference made up by irrigation. Compare also with rates at Chelyabinsk 300 – 600 spring wheat, up to 4000 for cabbage, 2300 potatoes, alfalfa 3000 m3/y/hect. That is 0.03 to 0.3 m/y (Sazykina personal communication data for irrigation in Step area). Spanish step 66% of Spanish step pasture/forage is irrigated (CIEMAT, 1999). UK experience requirement is 0.5 m/y needed, not all from irrigation. Bottom end of range in MAFF scheme 0.125 m/y to restore field capacity in one irrigation event.

Information points towards using upper end of range. There is no point in having an irrigation 'scenario' and then examining the case where we do not assume much irrigation. There is no need to be crop specific if we use near the upper end. Value adopted: 0.3 m/y.

*Infiltration, m/y* given by annual precipitation (c.0.4 m/y for ZBVII) plus irrigation (0.3 m/y) less potential evapo-transpiration by Thornthwaite (c 700 mm/y). Difference is small. To avoid salted soil, assume 0.1 m/y. (Applying Thornthwaite's formula using data from ERB2A suggested moiture site description deficit of 267 mm, matching our assumed 300 mm, and infiltration of 130 mm, matching our 100 mm (all per year).)

*Wet porosity:* Close to field capacity means wet porosity is close to total porosity. We have a single porosity model, therefore no distinction between water filled and effective capacity. Effective porosity is usually much lower than total. Value adopted: 0.2.

*Total porosity:* 0.5 (range 0.3 to 0.5)

*Soil thickness:* factors: ploughing depth 30 cm; chernozem is 60 cm thick; no need to have separate soil for pasture is because it is irrigated and may be ploughed at times, with crop rotation. Use 0.3 m since this is best for correspondence to root uptake, and measurement data.

*Soil grain density:* 2.65 Bouewer et al., (1978).

*Erosion rate:* Conservative to remove it, and effect is small, see Annex CIII.

### CI–1.2. INTERCEPTION FACTOR

Special consideration was given to this paramenter because of its perceived importance.

*Potential relationships:*

Link between interception and yield and/or standing biomass.

Is it element independent? Some evidence that cation interception higher than anion, but overall view taken was that this is of second order relative to other processes.

*Factors linkinginterception factor to other parameters/correlations:* rate of irrigation, translocation factor, plant morphology sometimes represented by LAI (leaf area index), standing biomass/timing of irrigation. Difficult to distinguish the radionuclide interception from the water interception. Agriculture data will give the water data, radio-ecology will give the radionuclide data. Positive correlation between standing biomass and timing of irrigation.

It was proposed to change $\mu_{crop}$ to represent the radionuclide interception not water, and may be element dependent. So it is defined as the fraction of radionuclide in spray irrigation water which is initially deposited on standing biomass.

Assumptions: irrigation is done when there is lots of standing biomass, ie only 60 days, July August. Prior to that the evapo-transpiration can be largely met by spring melt and rain. For 300 mm this means 5 mm per day irrigation intensity, which could be done in half an hour, i.e. 10 mm per hour, cf normal intensity cf 4–10 mm (Watkins, 1990). Thus, this is consistent with the irrigation practice and the seasonal requirement, as indicated by moisture deficit, which arises mostly in second half of growing season.

Resulting in consideration of crop types:

— vegetables, green and root;

— cereals, would not need 300 mm, nearer 150 mm, and only in July;

— pasture;

— fruits; advice from Fruits Working Group of BIOMASS suggested that fruit could have different interception from other crops.

There will be differences between crops for interception fraction, but cannot easily say how. Values include numbers up near to 100%.

*Conditioning:*

databases/references (e.g. Coughtrey et al., (1983); Watkins (1990)) range from 0.2 to 0.9. Caution that some data are for atmospheric deposition of particulate not irrigation, and data for biomass are very uncertain.

Potential causes/implications of extreme values. High values for dense morphology and low intensity, small droplet size, time taken between the application and the measurement. Implication of extreme assumption is not so great, only a linear implication for impact. And not enough to distinguish between crops.

*Encoding:*

At the first data meeting it was decided that the interception factor should have a value of 0.7 for all plant types noting that, for the most part, this would apply to more matured crops in July and August. Subsequently though, G Pröhl provided evidence from Pröhl and Müller (2000) that the interception factor depends upon the charge of the ion (Figure CII–1). This then led to the radionuclide dependent interception factors shown in Tables C28–C31.

Will need to take account of relationship to weathering rate.

For a biomass of 0.2 kg/m$^2$ dry weight, then values would be consistent with range given in IAEA-TECDOC-364 (IAEA, 1994).

*Relationship with Translocation and Weathering Rate:*

Distinguish standing biomass at time of cropping, and at average time irrigation occurs.

Discussion of data and the particular meaning of the quantities resulted in alternative conceptual model. New parameters: the fraction on outside which is aborbed to inside the plant, is fraction of material absorbed which is then translocated (Ftrans) to edible portion; fraction edible on plant surfaces, food processing losses for surface and internal fractions, and time between irrigation and cropping. These changes make application of data easier and take better account of real processes. See Annex CIII for detail.

### CI–1.3. ELEMENT/RADIONUCLIDE DEPENDENT DATA

Only limited consideration was possible within BIOMASS. References for values adopted are given in the table of the main text. Note that, without a real assessment of source term, it is not possible to identify the important and uncertain parameters for which close scrutiny under the protocol is appropriate.

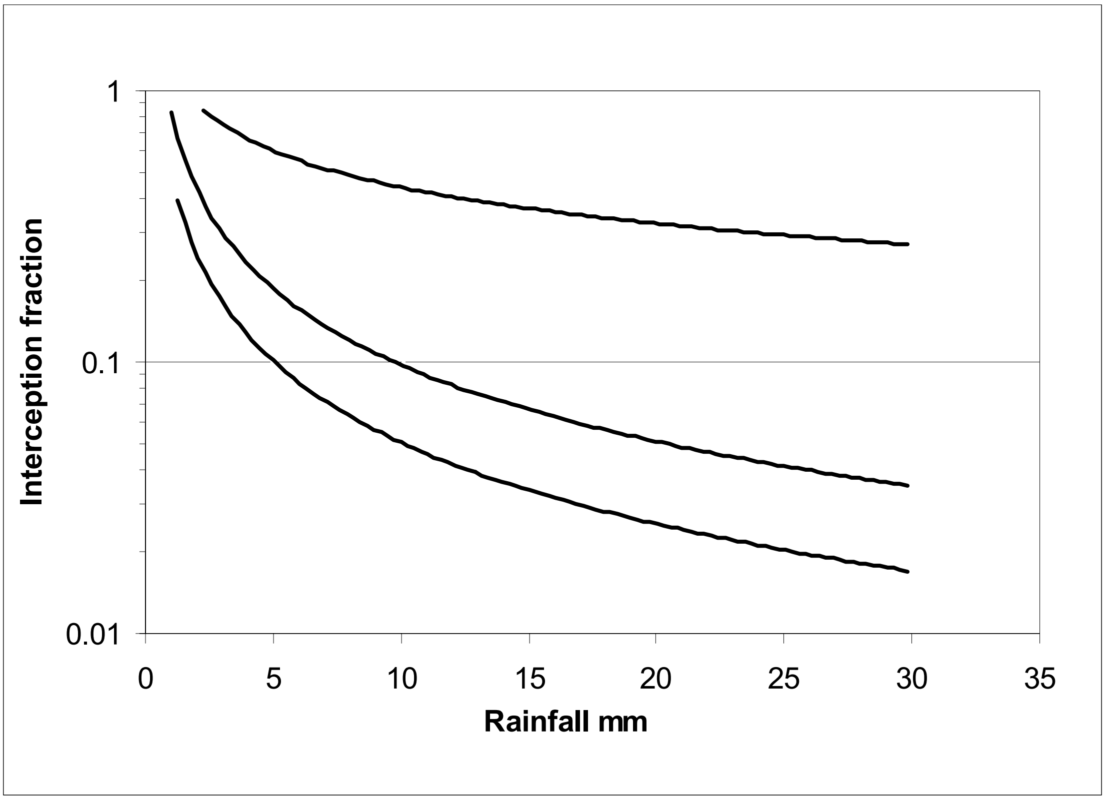


*FIG. CII–1. Interception of wet deposits as modelled by ECOSYS (for a yield-derived leaf area index =5). After Pröhl and Müller (1996).*

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# ANNEX CIII
# INVESTIGATION OF THE INFLUENCE OF ALTERNATIVE ASSUMPTIONS ON ERB2A

## CII–1. INTRODUCTION

The purpose of this note is to illustrate the impact of a number of alternative model assumptions on the doses calculated for ERB2A. The four examples are chosen to be illustrative of:

(i) conceptual model variation;

(ii) mathematical model variation; and

(iii) parameter value variation.

## CII–2. CONCEPTUAL MODEL VARIATION – CONSIDERATION OF SHEEP MILK IN PLACE OF COW'S MILK FOR I-129

The ERB2A model uses a transfer factor for I-129 to cow milk of 3.0E-3 d l-1 fw quoted from Smith et al., (1996) which in turn is taken from Ashton and Sumerling (1988) and Coughtrey et al., (1983–1985). According to IAEA/IUR (1994) the transfer factor for I-129 to sheep milk may be much higher than that to cows milk, ranging from 8.0E-2 to 9.4E-1, with an expected value of 4.9E-1 d l-1.

The higher transfer factor for I-129 to sheep milk has been modelled in ERB2A to investigate how this would affect the dose received from consumption of sheep milk rather than cow milk. All of the parameters associated with animal type and used in the calculation of I-129 dose from consumption of animal produce have also been modified to be consistent with sheep (see Table CIII–1). The human consumption rate of sheep milk is assumed to be the same as for cow's milk, the calculations being based on the livestock farming exposure group due to the high consumption rate of milk (740 l y-1). However, this implies a very rich diet.

Table CIII–2 compares the results achieved through modelling the consumption of sheep milk with those achieved through modelling the consumption of cow milk. Figure CIII–1 breaks the results down to the contributions to the I-129 concentration of the milk at equilibrium due to the animal’s consumption of water, fodder and soil and the inhalation of dust. The results show a 17 fold increase in total dose from consumption of sheep milk compared to that achieved through the consumption of cow milk.

The maximum dose to the livestock farming exposure group across all exposure pathways for I-129 is 4.9E-7 Sv y-1. The increase of approximately 1.2 E-6 Sv y-1 illustrated in Table CIII–2 may therefore lead to a substantial increase in total dose were sheep to be considered instead of cows. This may be reduced were the human consumption rates reduced to reflect the likelihood of a lower consumption rate of sheep milk in comparison to cow milk due to a higher calorific content.

TABLE CIII–1. PARAMETER VALUES MODIFIED FROM EXAMPLE 2A TO BE CONSISTENT WITH THE LIVESTOCK BEING SHEEP

| Parameter | Example 2A – cows | Variant 1 – sheep | Reference for Variant 1 |
|---|---|---|---|
| I-129 transfer factor to milk – ingestion | 3.0E-3 d $kg^{-1}$ fw | 4.9E-1 d $kg^{-1}$ fw | IAEA/IUR (1994) |
| Animal fodder consumption rate | 7.0E1 kg $d^{-1}$ fw | 5.6E0 kg $d^{-1}$ fw | based on dairy sheep, IAEA (1994)[a] |
| Animal water consumption rate | 7.0E-2 $m^3$ $d^{-1}$ | 8E-3 $m^3$ $d^{-1}$ | based on dairy sheep, IAEA (1994)[b] |
| Animal soil consumption rate | 6.0E-1 kg $d^{-1}$ wet soil | 4.8E-2 kg $d^{-1}$ wet soil | based on ERB2A, WD8 0.2[c] |
| Breathing rate | 5.4E0 $m^3$ $h^{-1}$ | 3.6E-1 $m^3$ $h^{-1}$ | Brown and Simmonds (1995) |
| Number of animals in unit area | 2.0E-4 | 5.0E-4 | Brown and Simmonds (1995) |

[a] in IAEA/IUR (1994) dairy sheep consumption is approximately 8% that of dairy cows, the consumption used in this variant is 8% that used in ERB2A;
[b] dairy sheep water consumption is quoted in IAEA (1994) as being between 5-8 l $d^{-1}$;
[c] represents the same proportion of fodder consumption as used in the ERB2A for dairy cattle, i.e. approximately 0.9%.

TABLE CIII–2. SENSITIVITY OF ERB2A TO VARIATIONS IN I-129 TRANSFER TO MILK

| | Cow milk | Sheep milk |
|---|---|---|
| Peak concentration in milk, Bq $kg^{-1}$ fw | 8.91E-4 | 1.49E-2 |
| Peak I-129 dose from consumption of milk, Sv $y^{-1}$ | 7.26E-8 | 1.22E-6 |

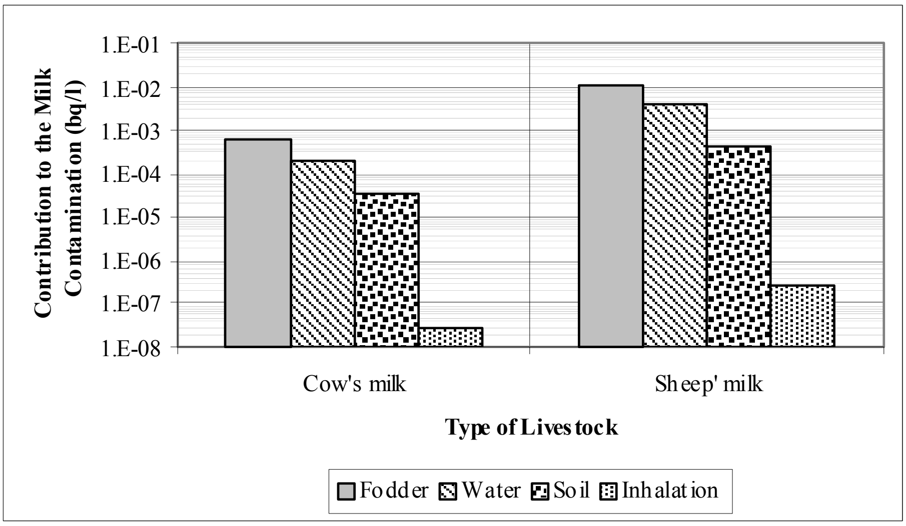


*FIG. CIII–1. Breakdown of I-129 Concentration of Milk Depending on the Source of Contamination at Equilibrium.*

CII–3. CONCEPTUAL MODEL VARIATION – CALCULATION OF DUST CONCENTRATION, EFFECT ON INHALATION DOSE

The concentration of radionuclides in the soil, from which the concentration in the air is derived, is based on the assumption of an even distribution throughout the 0.3 m deep soil compartment. The dust in the air is likely to originate from the soil surface. Within the first year, the short amount of time available for the radionuclides to migrate and mix within the soil means that they are likely to remain near the surface of the soil. The effect of assuming instantaneous mixing is therefore to mix the radionuclides that are likely to reside near the surface of the soil with the rest of the soil compartment, thereby reducing the calculated concentration in the dust and in the air.

The results achieved through assuming the radionuclides in the soil compartment to be concentrated in the first 1 cm of the soil during the first year in the calculation of the concentration in the air are shown in Table CIII–3, and Figure CIII–2. The results for the dose from exposure to dust include both the low and high dust conditions and are compared with the total dose at 1 year along with the corresponding results from the original model. The results are presented for the horticultural producer exposure group due to the high occupancy during high dust loading.

The results show that although the dose from dust inhalation increases by a factor of 30, there is very little impact on the total dose received at 1 y due to the total dose being dominated by other pathways.

TABLE CIII–3. COMPARISON OF THE ALTERNATIVE DUST CALCULATION AT 1 YEAR

| | I-129 | Np-237 | Tc-99 | Nb-94 |
|---|---|---|---|---|
| Results from concentrating radionuclides in the top 1 cm of soil for the dust | | | | |
| Dose from dust inhalation (Sv $y^{-1}$) | 2.27E-12 | 3.21E-9 | 4.30E-14 | 6.41E-12 |
| Total Dose (Sv $y^{-1}$) | 6.74E-7 | 7.33E-7 | 3.02E-9 | 1.56E-8 |
| Results from the original model | | | | |
| Dose from dust inhalation (Sv $y^{-1}$) | 7.57E-14 | 1.07E-10 | 1.43E-15 | 2.14E-013 |
| Total Dose (Sv $y^{-1}$) | 6.74E-7 | 7.30E-7 | 3.02E-9 | 1.56E-8 |

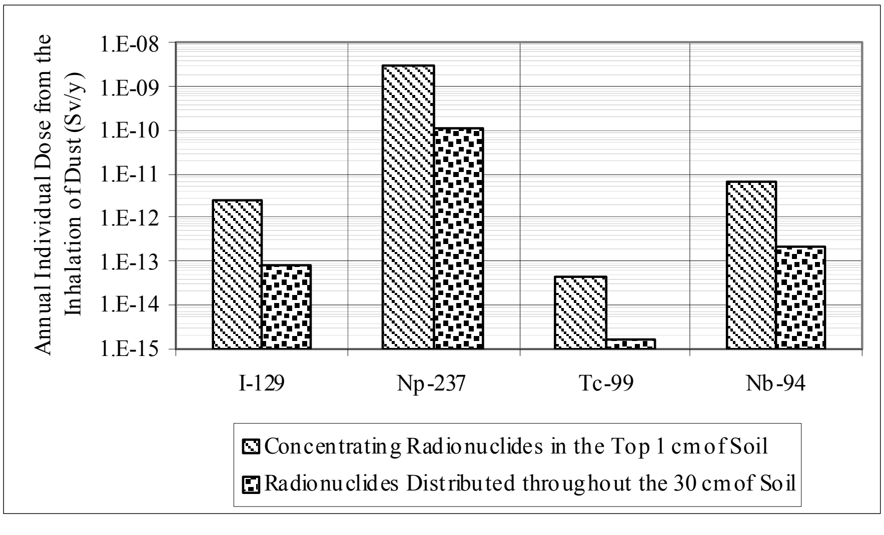


*FIG. CIII–2. Comparison of the Dose from Dust Calculated using the Original Model with those Calculated from Concentrating the Radionuclides in the top 1 cm of Soil at 1 Year.*

## CII–4. MATHEMATICAL MODEL VARIATION – ALTERNATIVE REPRESENTATIONS OF WEATHERING

The modelling approach to the weathering of external contamination due to the interception of irrigation water differs between crops and fodder for ERB2A.

The proposed equation for calculating the radionuclide concentration in crops represents weathering with the term e-WT. The exponential term indicates that the weathering process applies only after irrigation has ended and allows the influence of time between irrigation and harvest to be investigated.

The proposed equation for calculating the radionuclide concentration in fodder represents weathering with the term W-1. This assumes that irrigation and weathering are occurring simultaneously and continuously so that the assumed activity on the plant at the time of harvesting is the average over the year.

The mathematical representation of the alternatives is as follows:

### CII–4.1. HUMAN FOOD CROPS

The two methods of calculating the $C_{crop}$ term depending on how the weathering of intercepted radionuclides from the crop are:

$$C_{crop} = \frac{(F_{p2}CF_{crop} + F_{p1}S_{crop})C_s}{(1-\theta_t)\rho} + I_{crop}V_{irr}C_w\left(\frac{(1-F_{abs})e^{-WT}F_{p3}}{Y} + \frac{F_{abs}F_{p2}F_{trans}}{Y}\right)$$

or

$$C_{crop} = \frac{(F_{p2}CF_{crop} + F_{p1}S_{crop})C_s}{(1-\theta_t)\rho} + I_{crop}V_{irr}C_w\left(\frac{(1-F_{abs})\,F_{p3}}{W\,SB} + \frac{F_{abs}F_{p2}F_{trans}}{Y}\right)$$

where:

$F_{p2}$ is the fraction of the internal contamination associated with the edible part of the plant at harvest that is retained after food processing has occurred;

$CF_{crop}$ is the concentration factor from root uptake for the crop, Bq kg$^{-1}$ (fresh weight of crop)/Bq kg$^{-1}$ (dry weight of soil);

$F_{p1}$ is the fraction of external soil contamination on the edible part of the crop retained after food processing;

$S_{crop}$ is the soil contamination on the crop, kg (dry weight soil) kg$^{-1}$ (fresh weight of crop);

$I_{crop}$ is the fraction of radionuclide in spray irrigation water that is initially deposited on standing biomass;

$F_{abs}$ is the fraction of absorbed radionuclide initially deposited onto the plant surface that is absorbed from external surfaces into plant tissues;

$F_{p3}$ is the fraction external contamination from interception that is retained on the edible part of the crop after food processing;

$F_{trans}$ is the fraction of absorbed activity that is translocated to edible portion of plant by time of harvest (translocation fraction);

$Y$ is the wet weight edible yield obtained at harvest from the unit area irrigated, kg y$^{-1}$;

$W$ is the removal rate of radionuclide deposited on plant surface by irrigation by weathering processes (weathering rate) including mechanical weathering, wash-off and leaf fall, $y^{-1}$;
$T$ is the interval between irrigation and harvest, y;
$SB$ is the wet weight edible biomass obtained at harvest from the unit area irrigated, kg.
Note:

Equation 10a corresponds to the assumption that the delay between irrigation and cropping is best represented by explicit consideration of a specific delay time, *T*;

Equation 10b corresponds to the assumption that the best representation of this delay is to take the average.

The following points should also be noted:

- It is assumed that the crop can be contaminated due to:
  - internal uptake of contaminants from the cultivated soil compartment into the crop via the roots (represented by the $\frac{CF_{crop}C_s}{(1-\theta_t)\rho}$ term);
  - external contamination of the crop due to deposition of re-suspended sediment from the surface soil compartment (represented by the $\frac{S_{crop}C_s}{(1-\theta_t)\rho}$ term);
  - irrigation (represented by the $I_{crop}V_{irr}C_w$ term).
- It is assumed that contamination can be lost due to:
  - food preparation (represented by $F_{p1}$, $F_{p2}$ and $F_{p3}$ terms);
  - weathering of the external contamination to the soil (represented by the $e^{-WT}$ term).

## CII–4.2. FODDER/PASTURE

The $C_{fodd}$ term is calculated using the following equation:

$$C_{fodd} = \frac{(CF_{past} + S_{past})C_s}{(1-\theta_t)\rho} + \frac{I_{past}V_{irr}C_w}{SB_{past}W_{past} + SD\,ING_{fodd}}$$

where:

$CF_{past}$ is the concentration factor for pasture, Bq $kg^{-1}$ (fresh weight of pasture)/Bq $kg^{-1}$ (dry weight of soil);
$S_{past}$ is the soil contamination on pasture, kg (dry weight soil)/kg (fresh weight of pasture);
$I_{past}$ is the interception fraction for irrigation water on pasture;
$SB_{past}$ is the wet weight standing biomass of pasture obtained from the unit area irrigated, kg;
$W_{past}$ is the removal rate of radionuclide deposited on pasture surface by irrigation by weathering processes (weathering rate) including mechanical weathering, wash-off and leaf fall, $y^{-1}$;
$SD$ is the stocking density of the animals;
$ING_{fodd}$ is the consumption rate of fodder by the animal, kg (fresh weight) $y^{-1}$.

There is an apparent lack of consistency in the model between the way in which weathering is represented in food and pasture crops. However since pasture can be cropped continuously by grazing animals, the averaging approach is perhaps more appropriate, hence the choice in ERB2A. The impact of the different possible methods of representing the weathering of crops has been assessed by comparing the radionuclide concentrations of the crops, and the dose received from consumption of the crops. The calculations are based on the parameter values used in ERB2A, and the results are shown in Table CIII–4.

Note that Table CIII–4 presents the results achieved assuming the same amount of time between irrigation and harvest as in ERB2A. The effect of reducing the amount of time between irrigation and harvest is shown in Table CIII–5.

The results for the root vegetables show no difference between the mathematical representations of weathering due to there being no contribution from external intercepted radionuclides. The results for green vegetables and grain show that although representing weathering with the term e-WT results in slightly higher radionuclide concentrations in the crops, this has a minimal impact on the dose received from their consumption.

The effect of reducing time between irrigation and harvest is to decrease the time available for the weathering of radionuclides on external plant surfaces due to the interception of irrigation water. This means that there are more radionuclides on the crops from intercepted irrigation when the crops are harvested, resulting in higher crop concentrations and therefore higher doses (see Table CIII–5).

TABLE CIII–4. INFLUENCE OF THE DIFFERENT APPROACHES TO MODELLING WEATHERING ON THE CONCENTRATION OF RADIONUCLIDES IN CROPS AND THE DOSE RECEIVED FROM THE CRITICAL CONSUMPTION OF CROPS AT EQUILIBRIUM

| | | I-129 | Np-237 | Tc-99 | Nb-94 |
|---|---|---|---|---|---|
| Representation of Weathering | | Radionuclide concentration in crop (Bq kg$^{-1}$) | | | |
| Root vegetables | $e^{-WT}$ | 1.06E-3 | 3.01E-4 | 3.54E-3 | 3.82E-3 |
| | $W^{-1}$ | 1.06E-3 | 3.01E-4 | 3.54E-3 | 3.82E-3 |
| Green vegetables | $e^{-WT}$ | 1.08E-2 | 1.81E-2 | 6.77E-3 | 1.85E-2 |
| | $W^{-1}$ | 1.01E-2 | 1.71E-2 | 6.56E-3 | 1.74E-2 |
| Grain | $e^{-WT}$ | 7.76E-3 | 1.70E-3 | 5.77E-3 | 4.03E-3 |
| | $W^{-1}$ | 7.60E-3 | 1.44E-3 | 5.72E-3 | 3.78E-3 |
| | | Annual Individual Effective Dose Received from Eating Crops (Sv y$^{-1}$) | | | |
| Root vegetables | $e^{-WT}$ | 3.74E-8 | 1.06E-8 | 7.25E-10 | 2.08E-9 |
| | $W^{-1}$ | 3.74E-8 | 1.06E-8 | 7.25E-10 | 2.08E-9 |
| Green vegetables | $e^{-WT}$ | 3.43E-7 | 5.78E-7 | 1.26E-9 | 9.10E-9 |
| | $W^{-1}$ | 3.23E-7 | 5.44E-7 | 1.22E-9 | 8.58E-9 |
| Grain | $e^{-WT}$ | 4.01E-7 | 8.76E-8 | 1.74E-9 | 3.22E-9 |
| | $W^{-1}$ | 3.93E-7 | 7.45E-8 | 1.72E-9 | 3.02E-9 |

TABLE CIII–5. EFFECT OF REDUCING THE AMOUNT OF TIME BETWEEN IRRIGATION AND HARVEST ON THE CONCENTRATION OF RADIONUCLIDES IN CROPS AND THE TOTAL DOSE RECEIVED FROM THE CRITICAL CONSUMPTION OF CROPS AT EQUILIBRIUM

| | | I-129 | Np-237 | Tc-99 | Nb-94 |
|---|---|---|---|---|---|
| Time between irrigation and harvest (y) | | Radionuclide concentration in crop (Bq kg$^{-1}$) | | | |
| Root vegetables | 0.04 | 1.06E-3 | 3.01E-4 | 3.54E-3 | 3.82E-3 |
| | 0.02 | 1.06E-3 | 3.01E-4 | 3.54E-3 | 3.82E-3 |
| Green vegetables | 0.02 | 1.08E-2 | 1.81E-2 | 6.77E-3 | 1.85E-2 |
| | 0.01 | 1.09E-2 | 1.84E-2 | 6.82E-3 | 1.87E-2 |
| Grain | 0.075 | 7.76E-3 | 1.70E-3 | 5.77E-3 | 4.03E-3 |
| | 0.04 | 7.93E-3 | 1.98E-3 | 5.83E-3 | 4.32E-3 |
| | | Annual Individual Effective Dose Received from Eating Crops (Sv y$^{-1}$) | | | |
| Root vegetables | 0.04 | 3.74E-8 | 1.06E-8 | 7.25E-10 | 2.08E-9 |
| | 0.02 | 3.74E-8 | 1.06E-8 | 7.25E-10 | 2.08E-9 |
| Green vegetables | 0.02 | 3.43E-7 | 5.78E-7 | 1.26E-9 | 9.10E-9 |
| | 0.01 | 3.48E-7 | 5.86E-7 | 1.27E-9 | 9.22E-9 |
| Grain | 0.075 | 4.01E-7 | 8.76E-8 | 1.74E-9 | 3.22E-9 |
| | 0.04 | 4.10E-7 | 1.02E-7 | 1.75E-9 | 3.45E-9 |

## CII–5. MATHEMATICAL MODEL VARIATION – CROPPING LOSS REPRESENTATION AND EROSION

Table CIII–6 illustrates the transfer rates for the 4 different types of agriculture together with the total of the 4 transfer rates and the average of the 4 transfer rates. The results illustrate that in comparison to infiltration, cropping is not an important process. However, it is possible that realistic combinations of Kd and root uptake factors could make it important. If that were the case, further consideration would have to be given to the averaging of the cropping loss, assuming a crop rotation, especially where pasture is concerned.

Table CIII–6 also illustrates the importance of revisiting assumptions made during the development of a biosphere model when the context changes. In this case, the erosion transfer was ignored for I-129, Np-237 and Tc-99 on the basis that it is small in relation to the infiltration transfer. This argument is not true for Nb-94 which was included at a later point in the development of the model, as a change to the assessment context. However, the erosion transfer can still be screened out on the basis of significance. The maximum erosion transfer rate for Nb-94 very low (3.3E-4 y--1), this means that it will take a long time before it significantly affects the Nb-94 concentration in the soil, by which time biosphere change will need to be addressed.

## CII–6. CORRELATED PARAMETER VALUE VARIATION – Tc-99 ROOT UPTAKE FACTOR AND $K_d$

There is a large variation in the literature for the root uptake factor for Tc-99 ranging from 1.0E-01 to 5.0E+02 in the review undertaken by Smith et al., (1996). The high variation is due to the difference in the mobility of Tc-99 depending on its chemical form. Viewed simplistically, the more mobile the form of Tc-99 then the more likely it is to be available to plants for root uptake, resulting in a negative correlation between the root uptake factor and Kd.

TABLE CIII–6. TABLE OF RATE CONSTANTS, $y^{-1}$, FOR INFILTRATION, EROSION AND CROPPING

| Infiltration | | Erosion | | | | |
|---|---|---|---|---|---|---|
| I-129 | 2.5E-02 | Maximum | 3.3E-03 | | | |
| Np-237 | 8.3E-03 | Minimum | 5.7E-04 | | | |
| Tc-99 | 1.5E+00 | | | | | |
| Nb-94 | 2.8E-04 | | | | | |
| Cropping transfers | | | | | | |
| | Rootveg | Greenveg | Grain | Pasture | Combined | Combined/4 |
| I-129 | 2.4E-05 | 2.4E-05 | 3.2E-06 | 6.3E-05 | 1.1E-04 | 2.9E-05 |
| Np-237 | 3.9E-05 | 3.9E-05 | 2.2E-06 | 8.8E-05 | 1.7E-04 | 4.2E-05 |
| Tc-99 | 7.5E-02 | 7.5E-02 | 1.0E-02 | 1.3E-01 | 2.9E-01 | 7.2E-02 |
| Nb-94 | 2.0E-05 | 4.5E-06 | 1.8E-06 | 3.0E-05 | 5.7E-05 | 1.4E-05 |
| Total Transfers | | | | | | |
| I-129 | 2.5E-02 | 2.5E-02 | 2.5E-02 | 2.5E-02 | 2.5E-02 | 2.5E-02 |
| Np-237 | 8.4E-03 | 8.4E-03 | 8.3E-03 | 8.4E-03 | 8.5E-03 | 8.4E-03 |
| Tc-99 | 1.6E+00 | 1.6E+00 | 1.5E+00 | 1.6E+00 | 1.8E+00 | 1.6E+00 |
| Nb-94 | 3.0E-04 | 2.8E-04 | 2.8E-04 | 3.1E-04 | 3.4E-04 | 2.9E-04 |

The results calculated using Kd of 1.7E-5 $m^3$ $kg^{-1}$ and a root uptake factor of 10 are compared with those calculated using a less mobile form of Tc-99 with a Kd of 1.5E-3 $m^3$ $kg^{-1}$ and a root uptake factor of 1 in Table CIII–7. The doses are presented for the arable farming exposure group due to it being the adult exposure group receiving the highest dose from Tc-99.

The results illustrate that the more mobile form of Tc-99 results in lower concentrations in the crops due to a greater loss from the soil by infiltration. The more mobile form also takes less time to reach 90% of the maximum dose from crops.

TABLE CIII–7. EVALUATING THE INFLUENCE OF UNCERTAINTY SURROUNDING THE SOIL TO PLANT TRANSFER AND $K_d$ OF Tc-99 AT EQUILIBRIUM

| Result | Crop | Mobile Tc-99 | Less mobile Tc-99 |
|---|---|---|---|
| Tc-99 concentration in crop (Bq $kg^{-1}$ fw) | Root vegetables | 3.54E-3 | 3.49E-3 |
| | Green vegetables | 6.77E-3 | 6.72E-3 |
| | Grain | 5.77E-3 | 5.72E-3 |
| Dose from Tc-99 due to consumption of crop (Sv $y^{-1}$) | Root vegetables | 7.25E-10 | 7.14E-10 |
| | Green vegetables | 4.16E-10 | 4.13E-10 |
| | Grain | 1.74E-9 | 1.72E-9 |
| Time taken to reach 90% of maximum dose from crop (y) | Root vegetables | 2 | 14 |
| | Green vegetables | 1 | 10 |
| | Grain | 2 | 12 |
| Total dose to a representative member of the arable farming exposure group from Tc-99 (Sv $y^{-1}$) | | 3.66E-9 | 3.63E-9 |

## REFERENCES FOR ANNEX CIII


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# ANNEX CIV
# COMPLETION OF EXAMPLE REFERENCE BIOSPHERE 2A THROUGH INCORPORATION OF RADIONUCLIDE CONCENTRATIONS IN GROUNDWATER BASED ON A REALISTIC ASSESSMENT BASED SOURCE TERM

## CIV–1. INTRODUCTION

The output from groundwater modelling calculations has been kindly provided by EPRI (Kessler et al., 2000). This provides the time-dependent radionuclide concentrations in the groundwater for three of the four radionuclides considered in Example Reference Biosphere 2A (see Figure CIV–1). The incorporation of these data has been used to demonstrate the completion of ERB2A by substituting assessment derived radionuclide concentrations in groundwater for the unit activities (i.e. 1 Bq $m^{-3}$) previously used.

## CIV–2. EXPOSURE GROUP RESULTS

The above time-dependent source term was applied as input to the ERB2A reference biosphere model. A linear interpolation was used between the specified concentration values. The same source term can then be applied to calculate annual individual doses from all radionuclides and all of the exposure pathways for the five different exposure groups in ERB2A (Figure CIV–2). These results show that the results for all of the exposure groups lie approximately within an order of magnitude.

The highest dose is received by the infant exposure group (2.0E-6 Sv y-1 after 500 000 y) and is approximately four times that of the nearest adult exposure group (5.5E-7 Sv y-1 after 500 000 y). The dose to the infant exposure group is dominated by the dose from Np-237 which accounts for 2.0E-6 Sv y-1 after 500 000 y (see Figure CIV–3), compared to a maximum contribution of 3.5E-8 Sv y-1 from Tc-99 (after 400 000 y) and 5.3E-9 Sv y-1 from I-129 (after 500 000 y). Figure CIV–4 shows the consumption of green vegetables to be the primary source of exposure to Np-237 for the infant exposure group, and that drinking water, grain and root vegetables are also significant. Figure CIV–5 shows that the Np-237 contamination of green vegetables after 500 000 y is primarily due to the absorption of intercepted irrigation water.

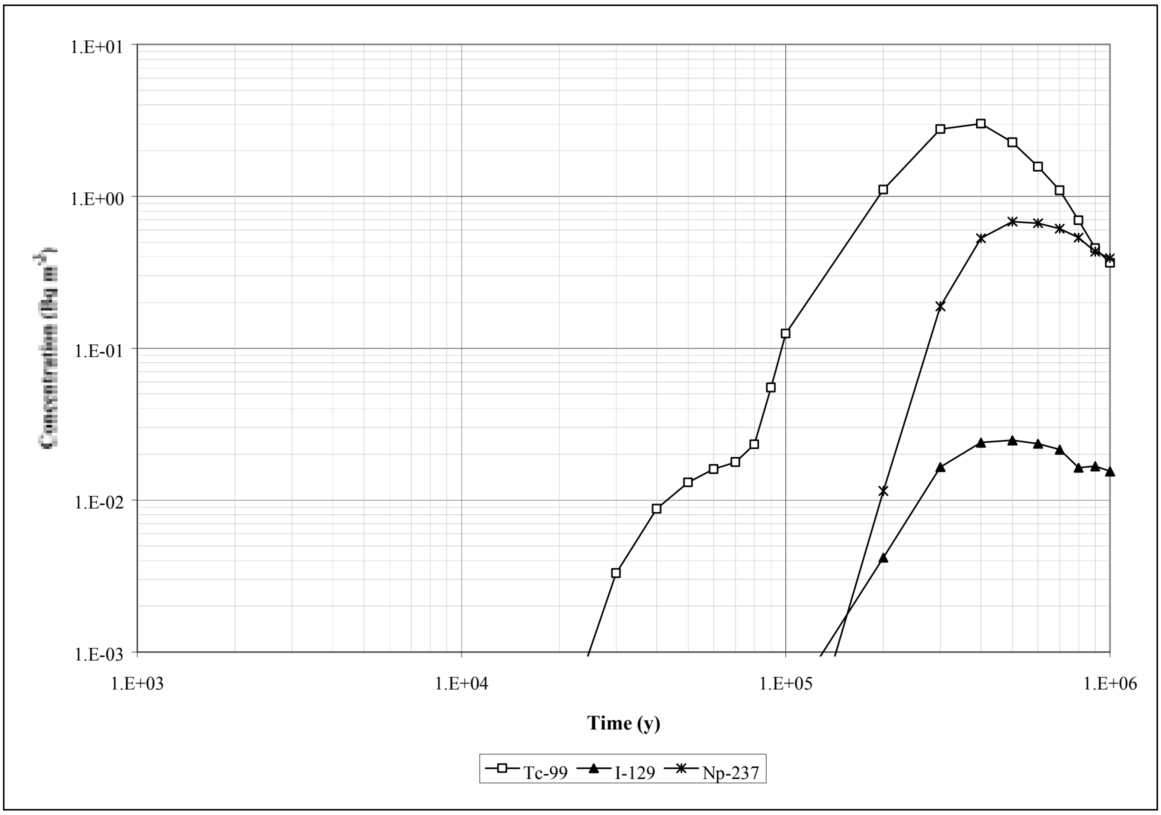


*FIG. CIV–1. Radionuclide Concentration in Groundwater, Providing a Realistic Assessment Based Source Term for Example Reference Biosphere 2A.*

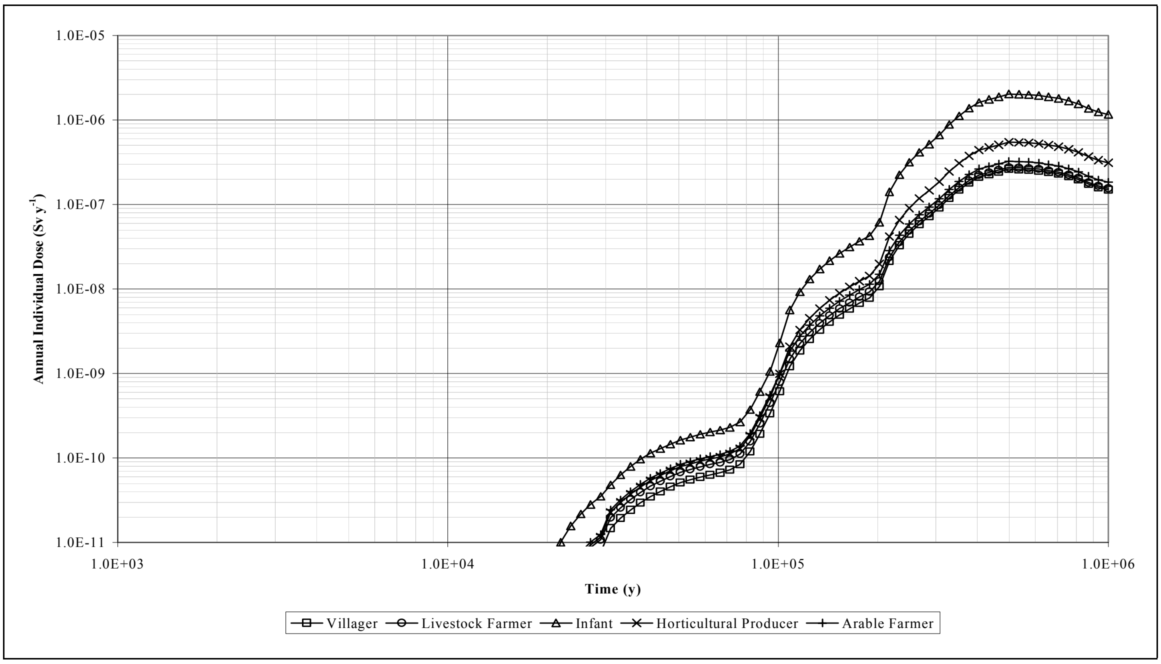


*FIG. CIV–2. Total Annual Individual Effective Doses for ERB2A Calculated Using a Realistic Assessment Based Source Term.*

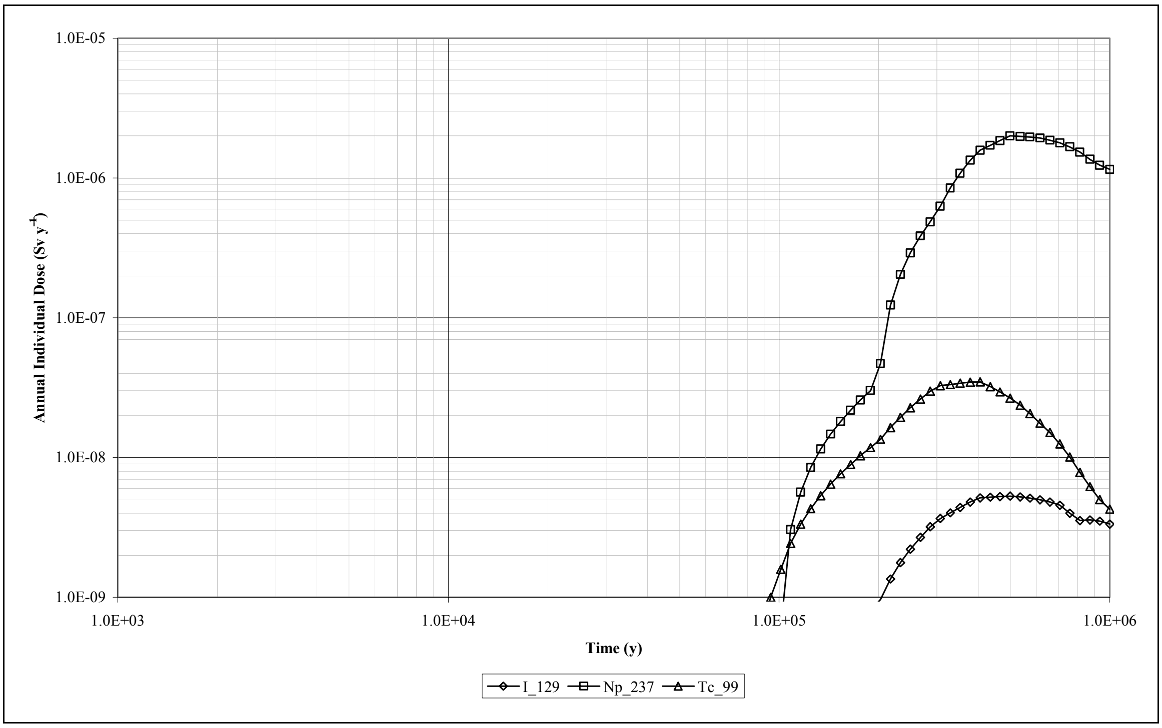


*FIG. CIV–3. Contribution of the Radionuclides to the Total Annual Individual Effective Dose to the Infant Exposure Group for ERB2A, Calculated Using a Realistic Assessment Based Source Term.*

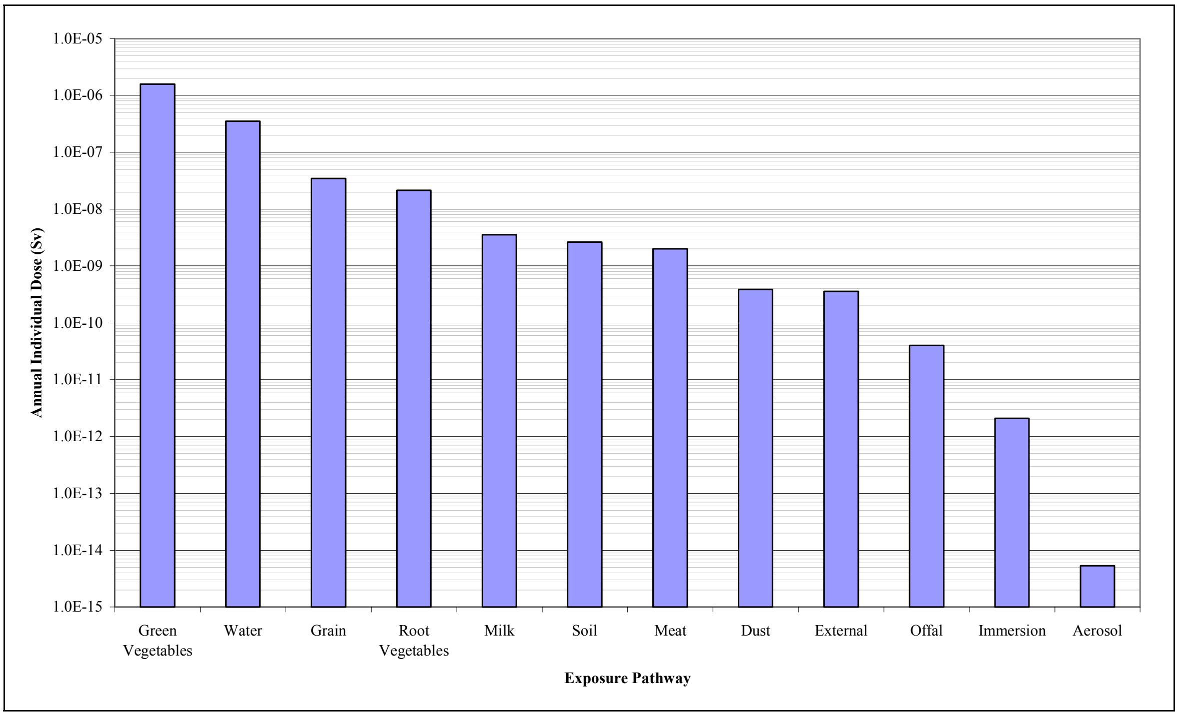


*FIG. CIV–4. Contribution of the Different Exposure Pathways to the Annual Individual Effective Dose from Np-237 to the Infant Exposure Group for ERB2A after 500 000 y, Calculated Using a Realistic Assessment Based Source Term.*

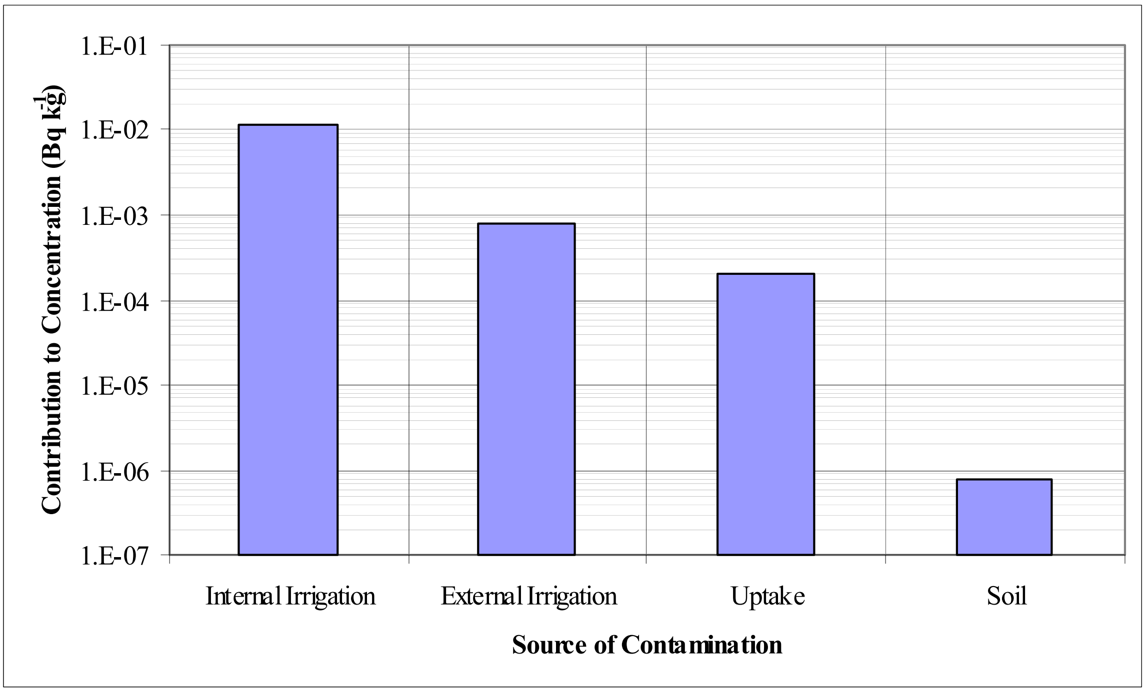


*FIG. CIV–5. Breakdown of the Np-237 Concentration of Green Vegetables after 500 000 y Depending on the Source of Contamination, Calculated After Applying a Realistic Assessment Based Source Term to ERB2A.*

## REFERENCE TO ANNEX CIV


KESSLER, J.H., DOERING, T.W., VLASITY, J.A., MCGUIRE, R.K., LONG, A., CHILDS, S., ROSS, B., SCHWARTZ, F., SHOESMITH, D., MASSARI, J., APTED, M., ZHOU, W., SUDICKY, E., STENHOUSE, M., Evaluation of the Candidate High-Level Radioactive Waste Repository at Yucca Mountain Using Total System Performance Assessment, Phase 5, Electric Power Research Institute Report Number 10000802, Palo Alto (2000).

## TERMINOLOGY DESCRIPTION

The following terms are used specifically within the BIOMASS Methodology (see also Table A1):

**Assessment biosphere**

"The set of assumptions and hypotheses that is necessary to provide a consistent basis for calculations of the radiological impact arising from long-term releases of repository-derived radionuclides into the biosphere."

**Biosphere system**

"A set of specific characteristics which describe the biotic and abiotic components of the surface environment and their relationships which are relevant to safety assessments of solid radioactive waste disposals."

**Conceptual model objects**

Distinct environmental objects or media explicitly included in the representation of radionuclide transport.

**Example reference biosphere**

One of the assessment biospheres developed within BIOMASS Theme 1 for the purpose of providing an international point of reference.

**Principal components (of the biosphere system)**

The principal components of the biosphere system were defined as: human activities; climate; topography; location; geographical extent; biota (or flora plus fauna); near-surface lithostratigraphy (or geology plus soils and sediments); and water bodies.

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## MEETINGS

BIOMASS Theme 1 Planning Meeting, Vienna, Austria: 3–5 June 1996

BIOMASS Theme 1 Task Group Meeting, Oxford, United Kingdom: 7–11 April 1997

BIOMASS Theme 1 Consultants' Meeting, Vienna, Austria: 16–20 June 1997

BIOMASS Theme 1 Consultants' Meeting, Vienna, Austria: 15–17 October 1997

BIOMASS Plenary and Working Group Meetings, Vienna, Austria: 20–24 October 1997

BIOMASS Theme 1 Consultants' Meeting, Vienna, Austria: 12–16 January 1998

BIOMASS Theme 1 Task Group Meeting, Henley-on-Thames, United Kingdom:
9–13 February 1998

BIOMASS Theme 1 Task Group Meeting, Vienna, Austria: 4–7 May 1998

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 5–9 October 1998

BIOMASS Theme 1 Consultants' Meeting, Vienna, Austria: 22–26 February 1999

BIOMASS Theme 1 Task Group Meeting, Henley-on-Thames, United Kingdom:
22–28 February 1999

BIOMASS Theme 1 Task Group Meeting, Madrid, Spain: 17–21 May 1999

BIOMASS Theme 1 Task Group Meeting, Washington DC, United States of America:
30 August – 3 September 1999

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 4–8 October 1999

BIOMASS Theme 1 Working Group Meeting, Vienna, Austria: 17–21 January 2000

BIOMASS Theme 1 Task Group Meeting, Warrington, United Kingdom: 19–23 June 2000

BIOMASS Theme 1 Working Group Meeting, Madrid, Spain: 19–23 June 2000

BIOMASS Research Co-ordination, Plenary and Working Group Meetings,
Vienna, Austria: 6–10 November 2000

BIOMASS Theme 1 Consultants' Meeting, Vienna, Austria: 19–23 March 2001