BIOPROTA

Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management

THEME 3 First Report on

Task 1: Guidance on Site-specific Biosphere Characterisation

and

Task 2: Experimental Research and Field Research Protocols

FOREWORD

Decisions on releases of radioactivity into the environment rely on a great variety of factors. Important among these is the prospective assessment of radionuclide behaviour in the environment, the associated migration and accumulation among and within specific environmental media, and the resulting environmental and human health impacts. Such assessments have been developed over several decades based on knowledge of the ecosystems involved, as well as monitoring of previous radionuclide releases to the environment, laboratory experiments and other research.

In some cases, problems arise in obtaining good data for these assessments. Particular difficulties arise in the case of long-lived radionuclides, because of the difficulty of setting up relatively long-term monitoring and experimental programmes, and because the biosphere systems themselves will change over the relevant periods, due to natural processes and the interference of mankind. It is also the case that, for one reason or another, much radio-ecological research has focussed on relatively few radionuclides, e.g. ^{90}Sr and ^{137}Cs. While this has been relevant, other radionuclides tend to dominate long-term impacts as may arise from releases from solid radioactive waste repositories, such as ^{129}I, ^{36}Cl, ^{79}Se, ^{99}Tc, ^{237}Np and others. This is obvious from the results of performance assessments for shallow and deep solid radioactive waste repositories.

However, the number of radionuclides involved is relatively small, and brief review suggests that the number of important processes associated with migration and accumulation in the biosphere, and the related radiation exposure of humans and other biota, is also relatively limited.

In addition, the long term sustainability of practices involving radioactive effluent discharges can only be considered in the light of a good understanding of such longer-lived radionuclides, even if the discharge inventories are dominated by shorter-lived radionuclides.

Several projects have been undertaken internationally to improve the long term assessment basis. Among these, the International Atomic Energy Agency's (IAEA's) BIOMASS Theme 1 has provided a clear basis for identifying, justifying and describing biosphere systems. The development of conceptual and mathematical models has been set out and a protocol developed for the application of data to these models. Following this, the IAEA EMRAS (Environmental Modelling for Radiation Safety) programme was established in 2003 to improve and maintain assessment abilities in the various member countries. Topics are focused on a few items and are relevant to radiological issues pertinent to the members. Several other international projects were set up through the European Commission and these further support long-term radiological assessments, in part, building on BIOMASS. These included:

- BIOCLIM – helps to define the biosphere systems in response to environmental (climate) change, as relevant to repository performance assessment;
- FASSET and now ERICA – developing the technical basis for assessing radiation impact on the environment;
- BIOMOSA - more specifically exploited the BIOMASS methodology on a regional basis.

BIOPROTA CONCEPT

None of the above projects directly addressed the uncertainties associated with the key processes in long-term dose assessments for the key radionuclides. BIOPROTA seeks to address those key uncertainties. It is understood that there are radio-ecological and other data and information issues that are common to specific assessments required in many countries. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and provide a transparent and traceable basis for the choices of parameter values, as well as for the wider interpretation of information used in assessments. The sponsors of BIOPROTA and other information is available at www.bioprota.com

General Objectives of BIOPROTA

To make available the best sources of information to justify modelling assumptions made within radiological assessments of radioactive waste management. Particular emphasis is to be placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities.

The project is to be driven by assessment needs identified from previous and on-going assessment projects. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions.

The modelling assumptions to be considered include the treatment of various features, events and processes (FEPs) of the systems under investigation, the mathematical representation of those FEPs and the choice of parameter values to adopt within those mathematical representations.

Objectives of Theme 3

Theme 3 of BIOPROTA has had two broad inter-related objectives. Under Task 1, the objective was to develop guidance on biosphere site-specific characterisation. Within this broad objective, the intention has been to identify the types of measurements to be made and to describe why they are useful. However, it was also recognized that biosphere site characterisation and underlying research both contribute to the needs of post-closure radiological performance assessment and that it would therefore be appropriate also to address protocols for research intended to support long-term biosphere assessments. Thus, the objective under Task 2 is to consider protocols for the design of research intended to support long-term biosphere assessments.

Although Tasks 1 and 2 can, to some degree, be pursued independently, they are so closely related that it has been decided to report progress on both of them in a single integrated document. As this is the first report on Theme 3, it comprises mainly an overview of the issues arising under the two tasks and provides recommendations on how the work should be developed. In the next phase of work, it is proposed that attention is concentrated on compiling information on real examples of site characterisation and protocols for research, site characterisation and monitoring. From this compilation and review activity, the intention is to both identify current best practice and to determine areas for which approaches need to be refined or extended, and for which new protocols need to be developed.

Recommended Citation

BIOPROTA (2006). Guidance on Site-specific Biosphere Characterisation and Experimental Research and Field Research Protocols. Main Contributors: E Leclerc-Cessac, M Thorne and G Thomson. Published on behalf of the BIOPROTA Steering Committee by Agence Nationale pour la Gestion des Dechets Radioactifs, ANDRA, Chatenay-Malabry, France.

Report History

V0.1 of the report was prepared by E Leclerc-Cessac (Andra, leader of Theme 3: Task 1) and M C Thorne (Mike Thorne and Associates Ltd, leader of Theme 3: Task 2), with support from the BIOPROTA Technical Secretariat, Enviros.

V0.2 of the report was modified by Elisabeth Leclerc-Cessac, based on feedback from participants.

V0.3 of the report was modified by M C Thorne (Mike Thorne and Associates Ltd) and Enviros, including further examples and information.

V1.0 was produced by Elisabeth Leclerc-Cessac and Enviros, based on feedback from the BIOPROTA Forum Meeting, Oxford, May 2006, and final comments form the BIOPROTA sponsoring organisations.

CONTENTS LIST

1 INTRODUCTION, SCOPE AND OBJECTIVES

Biosphere description embraces many disciplines generating data that have to be identified, described, measured and integrated in order to construct a descriptive ecosystem model that identifies and quantifies biotic and abiotic patterns and processes of importance for the ecosystem on a site. The biosphere description will be used to serve as the baseline model for devising a monitoring program to detect short-term disturbances caused by site investigations and construction of the repository. Furthermore, it will serve as a reference for future comparisons to determine more long-term effects or changes caused by the repository.

1.1 Example of the value of site-specific data for Cl-36

Taking into account site-specific data often enables the reduction of uncertainties in impact calculations, especially for models based on isotopic ratios. Consider, for example, a model of the transfer of ^{36}Cl within the biosphere which is based on the hypothesis that the behaviour of ^{36}Cl is the same as stable chlorine and so uses a specific activity model. In such a model, the key parameter is the concentration of stable chlorine within each component of the environment and especially in water. Andra has measured chlorine concentrations in rivers close to its sites in order to adapt the model [Leclerc-Cessac, 2005]. Thus, biosphere dose conversion factors, calculated with a specific activity model, can be reduced by up to around an order of magnitude when the stable chloride content in the river increases (Figure 1).

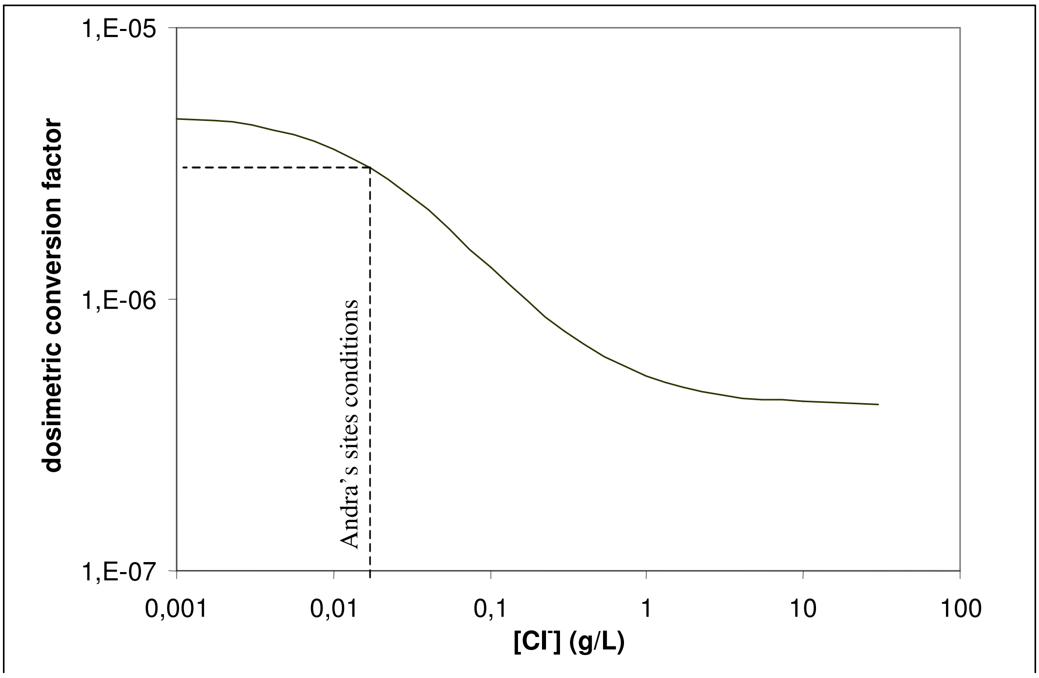


Figure 1: Influence of chloride river concentration on release to dose conversion factor ((Sv/y)/Bq/l))

Nevertheless, Sheppard [2005] states that site-specific transfer parameter values should not be used to the exclusion of other available data because transfer parameters are inherently variable and using a few site-specific data to the exclusion of all other data may decrease accuracy. The aim is then to collect various data from the site to represent the variability in site environmental conditions and evaluate these data in the context of more general environmental variability. Thus, the uncertainties can be obtained by taking into account both site-specific data and also other data relevant to the site.

1.2 Detailed Objectives of Theme 3: Task 1

The objectives of BIOPROTA Theme 3, Task 1 are to develop guidance on biosphere site-specific characterisation for long-term Performance Assessments.

The intention is to:

- Develop a list of parameters that are of principal importance to long-term performance assessments for key elements defined within BIOPROTA (cf. chapter 3), taking into account information and analyses arising from other tasks within BIOPROTA and both the structure of and results of applying the BIOMASS methodology;
- Identify those aspects of site characterisation that are relevant to determination of values of those parameters, taking spatial and temporal variability into account ;
- Identify what type of measurements should be made in order to determine values of the key parameters.

The last of these points is closely related to the protocols that should be used for making such measurements. This is the topic of Theme 3, Task 2.

1.2 Detailed Objectives of Theme 3: Task 2

The overall objective of BIOPROTA Theme 3, Task 2 is to develop protocols for the design of research intended to support long-term biosphere performance assessments. However, in order to complement Theme 3, Task 1 this scope is extended to cover protocols for underlying research, site characterisation and monitoring. Thus, the detailed objectives are:

- To identify the types of measurements that should be made in research, site characterisation and monitoring;
- To review the protocols that are currently available for making these types of measurements;
- To comment on the ranges of applicability of the available protocols;
- To identify deficiencies in available protocols, e.g. in terms of their ranges of applicability and in respect of their effectiveness in determining values of the quantities of interest;
- To make recommendations as to what protocols are likely to be most appropriate in different circumstances and on types of measurements for which enhancements of existing protocols or new protocols are required.

1.3 Relationship to other BIOPROTA Themes

BIOPROTA consists of a number of separate Themes, namely:-

- Theme 1 – Development of a specialised database;
- Theme 2 – Modelling, testing and development;
- Theme 3 – Site characterisation, experiments and monitoring.

These Themes are not independent and several interactions and dependencies exist between them.

Three fundamental questions can be asked, one from each theme, as indicated below. Answering the first two questions enables the focussing of attention on those parameters that are currently characterised with a high degree of variability or uncertainty and yet are considered to be key parameters in the overall estimation of radiological impact, bearing in mind that radiological impact may be addressed through several different measures of performance relative to both human health and the environment as a whole. The answer to the last question is what this Theme seeks to address. In this regard, the overall output from BIOPROTA should enable the planning of a focussed and cost-effective biosphere characterisation programme with a clear and logical audit trail.

Theme 1 What is the quality and variability of data available to assessment biospheres?

Theme 2 Which biosphere parameters is the estimation of impact sensitive to?

Theme 3 What are the best methods for characterising key biosphere parameters?

Site characterisation activities vary in nature, sequence and timing, and therefore other considerations may lead characterisation programmes to differ from the simple linear approach outlined above. Further discussion on this is contained within the report.

It is noted that Theme 2 contains 6 tasks, several of which are relevant to considerations of biosphere characterisation. BIOMASS also contains information that is relevant to aspects of questions above which may not be directly addressed within BIOPROTA, but may require consideration in order that an appropriate response can be given.

2 RELATIONSHIPS BETWEEN RESEARCH AND SITE CHARACTERISATION

It should be recognized that distinctions between experimental studies, site investigation activities and monitoring activities are not clearly defined. For example, experimental studies may use environmental media extracted from specific sites and field plot or hillslope experiments may be conducted *in situ* at the sites of interest or closely adjacent to them. Furthermore, both site investigation and monitoring activities may be modified or extended in scope for the purpose of providing useful experimental data or to establish an environmental context in which experimental results are obtained. There is also no clear dividing line between site investigation and monitoring. For example, a site investigation may include an initial baseline survey, followed by selective sequences of sampling to reveal time trends in parameters measured during the baseline survey. It is debatable whether such selective sequences of sampling should be regarded as part of site investigation or monitoring, particularly as they may extend through into the operational and post-closure phases of repository development.

A more useful distinction may be into the types of activities that may take place at different stages in a repository development programme. In broad terms, the following phases can be distinguished.

Before site selection: When no sites have been selected, generic research activities can be undertaken. These may relate to studies of processes that are thought likely to be of interest when sites are selected. In this phase, experimental research can be used to inform conceptual and mathematical model development. In addition, measurements of parameter values can be undertaken, where it is believed that these parameter values will be of broad applicability, e.g. plant:soil concentration ratios for specific radionuclides in a diversity of soil types to explore how soil texture, mineralogy, water status and other aspects affect radionuclide uptake by plants. It will be recognized from this example, that the distinction between exploring conceptual modelling issues and the provision of parameter values within a particular conceptual or mathematical framework is not clear cut. The identification of new relationships or the refutation of previously assumed ones may arise from data analysis. Conversely, the conceptual framework adopted will influence the types of measurements made, e.g. time series or point of harvest measurements of radionuclide uptake in crops.

During site selection: It is likely that approaches to site selection will vary from country to country, but it can be anticipated that in the majority of cases prior to selecting a site for repository development several may be considered. The general pattern of investigations will not differ substantially whether one or several sites are being investigated. Part of the screening process to reduce the number of candidate site may involve comparative assessments to be undertaken which would require an understanding of the characteristics of each site and its environs to be developed. There may also be the requirement to undertake more formal assessments such as a Strategic Environmental Assessment and/or an Environmental Impact Assessment which will also require a degree of characterisation to be undertaken.

After site selection: Generic studies may continue after site selection. However, there will be an increased emphasis on investigations at the site or sites selected. The variety of types of investigation is likely to be substantially wider than during the period before site selection. The various types of investigations will include:

- Overall investigations to demonstrate a general understanding of the characteristics of the site and its environs, to demonstrate a general appreciation of the nature of the local environment. Such investigations are likely to be tied closely to the requirement for baseline surveys in the context of Environmental Impact Assessment;
- Studies on processes occurring at the site that are not well-developed (if at all) in the pre-existing generic conceptual and mathematical models. For example, if earlier work had been directed toward agricultural environments and mineral soils, whereas the site area included an extensive area of semi-natural environment dominated by peat soils, there would be a need to extend the generic model and this might most conveniently be done by reference to site-specific data;
- Confirmation that environmental characteristics at the site fall within the range for which the generic model has been developed. For example, stable selenium concentrations might be measured in soils to confirm an underlying generic assumption that the biosphere in the repository area would not be selenium deficient;
- Measurement of parameter values at the site appropriate for use in performance assessment studies. In this context, it should be recognized that a hierarchy of models may be used. Thus, this requirement could relate to spatially and temporally extensive studies of water flow and hydrochemistry to calibrate a detailed physically based, surface-water catchment, hydrological model or to the measurement of plant:soil concentration ratios at harvest in field conditions for direct use in an assessment model.

After site acceptance: Studies undertaken after site selection will contribute to the development of a safety case used to justify a license for repository construction. However, licensing of such a repository to receive radioactive waste, to eventually be closed and finally for the area to be utilized for other purposes beyond the end of the post-closure monitoring period will all require further regulatory decisions to be underpinned by appropriate safety analyses. Thus, research and monitoring activities undertaken throughout the construction, operation, closure and post-closure maintenance periods can all make a contribution to licensing decisions.

Although it is intended to focus attention here on the period before site selection, the iterative nature of performance assessment suggests that the work developed here has relevance up to the point at which the site is released from regulatory control.

In all the above contexts, it should be kept in mind that the characteristics of a site at the present day may be related to the characteristics that will exist after repository closure, but are unlikely to be identical to those characteristics. Therefore, studies on sites at the present day will generally provide a basis for data abstraction and generalization to underpin a post-closure performance assessment that is robust against changes in those site characteristics. In this context, it is important to recognize that a limited number of measurements of values of a parameter in a specific site context should not necessarily outweigh a generic parameter value and associated range derived from a wide variety of studies, as the particular site context in which the measurements were made may not persist into the post-closure period.

Performance assessments for engineered radioactive waste facilities are normally required to be undertaken for extended periods of time due both to the long biosphere return times that may typify groundwater discharge from a deep geological repository and/or the long-lived nature of some of radionuclides within the waste.

This in turn leads to the conclusion that biosphere conditions that are relevant to the period when exposure calculations are of interest may be wholly different to those that exist at the time when the repository site investigation programme is undertaken. The significance of this is linked to the regulatory requirements that the developer is to be judged against and whether they are prescriptive (e.g. USA) or non-prescriptive (e.g. UK) with regards to the exposure scenarios and environmental conditions that are to be considered within the assessment calculations.

For situations in which an assessment of the importance of significant environmental changes on resultant biosphere doses is required to be undertaken, the following approaches can be distinguished.

1. Focus most effort on calculations associated with the present-day biosphere conditions in order to reduce the amount of parameter variability. Undertake sensitivity analyses on the implications of other potential environmental conditions.
2. Explore the importance of significant environmental changes through a central scenario which considers a series or sequence of varying environmental conditions. In this case biosphere characterisation of the variant environmental conditions could be obtained from other repository programmes (should these biosphere conditions map on to the central scenario) or by characterisation of present-day environmental conditions at different locations that would provide analogues of potential future conditions at the site of interest.

3 BIOSPHERE CHARACTERISATION

3.1 The Role and Scope of Site Characterisation

Theme 3 Task 1 involves developing guidance on how to characterise sites to facilitate the biosphere aspect of a Performance Assessment, e.g. through soil characterisation, studies of elemental and contaminant mobility, phyto-availability of elements and contaminants, mineralogy, amongst others. It can also provide inputs to an EIA which may be required for the construction of a facility, and may prevent the need to undertake the same characterisation activities twice (implied here is a description of the initial state in order to assess the impact of any proposed operation or the development of an installation, including characterisation of the physical and biological environments, covering geology, hydrology, climate, human populations, and the distribution and abundance of animal and plant species).

Site characterisation is needed to quantify abiotic and biotic aspects of radionuclide and chemical transfer processes. In BIOPROTA, the analyses of processes are focused on a limited number of key elements which are H, B, C, Cl, Se, Tc, Nb, Sn, I, Pb, Np and U.

3.2 Protocols for use in Research, Site Characterisation and Monitoring

In order to discuss the protocols required for experimental and monitoring studies, it is appropriate to classify the various types of experimental and monitoring studies that may be undertaken. At this stage it is not appropriate to discuss the detailed specifications of field and laboratory activities as it is considered that these will be highly dependent on the national context and site conditions. In this context, it is useful to consider that radionuclides may enter the biosphere through:

- Natural groundwater discharge;
- Groundwater abstraction from wells and boreholes;
- Transport of radioactively contaminated gas;
- Natural disruptive events;
- Human intrusion into the repository or its environs.

Of these, the first three are of greatest interest in the context of experimental studies and monitoring. Therefore, it is these pathways that are discussed below.

3.3 Prioritising resources for Biosphere Characterisation

An initial task of the Theme 3 Group is to constrain the characterisation activities based on a sound understanding of parameters that have a wide range of variability and/or uncertainty and also that are important in determining the estimation of potential exposure.

The system description approach developed as part of the BIOMASS methodology is considered to provide a convenient method of organising the system analysis and so is adopted here as a framework. Further input is taken from BIOPROTA Themes 1 and 2 in order to further prioritise by seeking to answer the following two questions.

1. *What is the quality and variability of data available to assessment biospheres?*

Within BIOPROTA Theme 1, a Specialised Database is being developed to compile the results of a critical review of the available literature containing information on the behaviour of those radionuclides considered within BIOPROTA (Cl-36, Se-79, Tc-99, I-

129, Np-237, and U-238 and its daughters). The Specialised Database contains the following information: Radionuclide half-lives; Dose coefficients; Soil data; Soil-plant interactions; Plant data; Animal data; and, Aquatic environment data [BIOPROTA, 2006].

The Specialised Database will enable consideration to be initially focused on those parameters for which it is shown that the available data are either of low quality (i.e. inappropriately or inadequately quantified) or highly variable (i.e. uncertain).

2. *Which biosphere parameters is the estimation of impact sensitive to?*

The series of Tasks comprising Theme 2 provide a ready means of further constraining effort by enabling the Specialised Database to be filtered. Of particular importance are likely to be: Task 1 (Model Review and Comparison for Spray Irrigation Pathway); Task 2 (Modelling the Inhalation Exposure Pathway); Task 3 (Model Review and Comparison for C-14 Dose Assessment); Task 4 (Model Intercomparison with Focus on Accumulation in Soil) and, Task 7 (Modelling Processes in the Geosphere Biosphere Interface Zone, GBIZ).

One important point to note is that biosphere characterisation for repository development is not a new discipline and substantial amounts of work have already been undertaken in several locations. Therefore, review of previous approaches to characterisation and those currently being develops affords an opportune means of discussing issues of relevance to BIOPROTA. Consideration of the characterisation programme previously undertaken by Nirex in the Sellafield area, as well as that currently being undertaken by SKB around Forsmark, Simpevarp and Laxemar, reveals that these programmes include an initial step to develop a historical description, in order to put the characterisation of the present-day surface environment into context [Thorne, 2006]. Although this approach is not specifically discussed here, it is considered that there is merit in providing a historical account of characteristics (where appropriate) before describing the present-day conditions and finally determining how the characteristics may be represented within mathematical models. Further discussion on this is contained in Thorne [2006].

An overview of the various phases of repository development with reference to biosphere characterisation has been given in Section 2 and another important consideration is the iteration between periods of active characterisation tasks (e.g. field mapping) and periods of interpretation and analysis (e.g. development of conceptual and mathematical models). Such periods could run sequentially, but, in practice, considerations of timescale and efficient use of resources mean that the two types of activity will overlap in time. Nirex is undertaking a Geosphere Characterisation Project as part of its studies to assess the viability of a Phased Geological Repository within the UK [Nirex, 2005]. As part of this study and based on observations of the ongoing SKB programme, Nirex has proposed a staged approach to investigation in which data freezes occur during the continuing investigation activities, in order that interpretation activities can be undertaken on a well-defined observational basis, as shown below.

Stage	Stage description	Sub-stage description	Data freeze
0	Desk study	-	-
1.1	Initial site investigations	Regional surveys	1
1.2		Initial boreholes	2
2.1	Detailed site investigations	Drilling and regional surveys	3
2.2			4
2.3		Post-completion testing	5
2.4		Establish baseline	-
3	Man-access underground investigations	-	-

In the Nirex scheme, it is assumed that sites for investigation would be selected at the end of Stage 0. At the end of Stage 2.4 it is assumed that the site suitability has been confirmed, authorisations obtained and repository construction commences.

Both the approaches proposed by Nirex [e.g. Nirex, 2005] and that currently being utilised by SKB [e.g. SKB, 2001] recognise the importance of the development of a sequence of descriptive site models (e.g. relating to geology, hydrogeology, hydrochemistry, rock mechanics) to describe in a logical and hierarchical manner those issues that will be required to be considered within a Performance Assessment [e.g. Lindborg, 2005a; b; 2006].

In order to make more transparent the generic discussion presented here, iterations between characterisation and interpretation are not explicitly discussed. Such a simplification is deemed appropriate, as the detailed scheduling of characterisation and interpretation tasks will be dependent on a host of variables such as the nature and location of site and the requirements of the licensing process against which the repository development is being undertaken. A generic discussion involving such considerations is not considered to be helpful at this stage within Theme 3. Instead, the following Type I biosphere components developed within BIOMASS are used as a means of structuring the biosphere description:

- Climate and Atmosphere;
- Near-surface lithostratigraphy;
- Topography;
- Water bodies;
- Biota (Flora and Fauna);
- Human community.

Each of these components is recognised as having a number of characteristics and these were tabulated within BIOMASS as a checklist. The biosphere characterisation by Andra at Meuse/Haute-Marne used the BIOMASS components as a means of framing the descriptive process and although the discipline-focussed approach of SKB has some differences it also has many similarities.

Below is a discussion of the importance of each of these components and characteristics and their perceived relevance to Theme 3. The discussion uses information from other BIOPROTA tasks in order to focus attention on those component characteristics that are considered to be of primary importance to the estimation of potential radiological impacts in a Performance Assessment.

3.3.1 Climate and Atmosphere

Climate characteristics are usually described by meteorological data referring to a specific period of time and location. *Precipitation* is considered as a characteristic of primary importance to the estimation of potential impact in a Performance Assessment because of the need to establish both a regional-scale water balance (e.g. to determine the interaction between surface water bodies and near-surface and surface water sources) and also a detailed soil moisture balance (e.g. to determine whether there is likely to be a requirement for irrigation). *Temperature* and *Solar radiation* are also considered to be of primary importance and have a bearing on the calculation of water balance (e.g. calculation of potential evapotranspiration), type of agriculture that is practised within the biosphere and also on the nature of human activities. *Pressure* and *Wind speed and direction* are not viewed as characteristics of primary importance to Performance Assessment calculations, however, they may be needed to derive input parameters or they may contribute to the overall understanding of climate characteristics (of course they are likely to be required to undertake an operational radiological impact assessment, if releases of radionuclides to atmosphere may occur).

The characterisation of present-day climatic conditions, taking into account periodic and aperiodic variations that occur on these timescales, requires the analysis of long-series (many decades) measurements of meteorological data. The long-term nature of Performance Assessments (many millennia) leads to the need to define several sets of climatic conditions, each of which is determined by long series of meteorological data.

Despite the previous comments on the need for parameters based on long-term trends, the analysis of temporal variability is also relevant in order that the importance of the shorter-term variability can be assessed and included in the impact calculations where appropriate. The types of processes of potential relevance have been identified in the BIOCLIM Project. For example, various natural events, such as flooding (caused by extreme rainfall events), which can occur with differing severity on a series of different timescales, may need to be included, either explicitly or implicitly, in the assessment calculations.

The most important characteristics of spatial variability are considered to be those associated with *Altitudinal* and *Aspect-related* variations. For example, if the biosphere under consideration is a valley then there may be different microclimates established at the base of the valley and higher up on the valley sides. *Latitudinal* and *Longitudinal* variations across the study area appropriate to a single site are considered to be of minor importance, but these factors could be of considerable importance in contexts where site selection is being undertaken on a national or regional basis.

In terms of the necessary methods of acquiring such data, use can be made of the parameters collected by automatic weather stations which commonly collect data on temperature, precipitation, sunshine hours and wind speed and direction. As has been noted previously the nature of Performance Assessments is such that long-term measurements are often used in order to determine parameters.

Although data from local meteorological stations may provide useful input, the possibility for variability on a local-scale due to altitude and aspect should not be overlooked. Therefore, it may be necessary to install several meteorological stations as part of a site characterisation programme. The need for long-term measurements means that meteorological stations should be established at an early period within the site characterisation programme. For example, SKB's approach to site characterisation states that long-term time series monitoring programmes should be established during the initial phases of characterisation [SKB, 2001].

It should also be noted that there is often a need to describe or reconstruct previous climate states in order to provide a complete description of the range of potential climatic conditions at a site. If climate change is required to be considered within the Performance Assessment, then it is possible that modelling studies may need to be undertaken in order to develop projections of climate change that can be suitably downscaled to the area of interest. Furthermore, local palaeo-environmental investigations may need to be undertaken, e.g. palynological, coleopteran and textural studies of sediment cores, to inform palaeo-climatic reconstructions.

3.3.2 Near-surface lithostratigraphy

Characterisation of the near-surface *Geology* is seen as being of primary importance and will have a significant impact on the estimation of potential impact in a Performance Assessment.

The determination of the extent and nature of the geological strata and *Stratification* of the soils and sediments is a necessary first step in developing an understanding of the biosphere system. Delineating the extent of overlying unconsolidated sediments and locating the position of rockhead is an important process the complexity of which can be related to local characteristics. For example, in Sweden the relatively thin cover of unconsolidated sediments means that rockhead can be located and its characteristics investigated at key locations by constructing shallow trenches, whereas in the UK the thickness of unconsolidated sediments may reach 50 m or more making trenching impossible [Thorne, 2006]. More generally, *Stratification* can be explored through a combination of unintrusive surveying (e.g. geophysical approaches) and intrusive studies (e.g. trial pit and borehole investigations). In coastal locations, it may be important to be able to interpret on-shore and off-shore geological data in a consistent manner which may require specific data acquisition techniques. The interfacial region between the on-shore and off-shore areas may be particularly difficult to investigate, because rapid structural changes may be anticipated in this area and available survey techniques may be difficult to deploy effectively. During initial stages of investigations the use of existing geological maps may suffice, but these are highly unlikely to be able to provide the data that would be required to develop 3-D geological model of sufficient robustness to support a repository characterisation programme.

The amount of resources assigned to *Edaphology* may to some extent depend on the calculation endpoints considered within the assessment context and whether environmental impact is included (see discussion on Biota in Section 3.3.5). However, it can generally be expected that at the very minimum it will be required to map the soil types across the survey area in order to support the development of hydrogeological modelling and consideration of exploitation of the area in the future by humans. An example of the classification of soil types is summarised below in Table 3.1 following the site investigations and associated studies Andra is currently engaged in the Meuse/Haute-Marne site in the Northeast of France.

Determining the *Composition* and *Texture* of the soils and the sediments and *Mineralogy* of the geological strata has an important bearing on the potential for groundwater flow and on the retention of contaminants, and these data can also inform conjectures as to the likely nature of future soil development, especially when considering *Weathering* and *Erodability*. *Erodability* on a wider scale may also be of significance at coastal locations, where coastline movement may be of concern.

Table 3.1: Zonal Soil Types for Northeast France

State	Description	Soil type
Temperate	Natural soils are often Brown Earths. However, these have been substantially modified by long-term agricultural activities. Well-drained, deep soils are characteristic.	Forest Brown Earths Agricultural soils
Boreal	Soils characterised by slow decomposition rates of the organic matter, marked acidity, depletion of minerals. Development of more extensive range of organic soils in wetlands.	Podzolic soils
Glacial	Shallow soils characterised by very slow decomposition rates of the organic matter, marked acidity, depletion of minerals. Extensive organic soils in wetlands. Substantial cryoturbation structures due to seasonal freezing and the development of permafrost.	Tundra humus soils

Andra took 9 samples of local soils around the Meuse/Haute-Marne site, categorised them into the 3 soil types noted above and used samples for batch and column experiments in order to measure sorption coefficients

Identification of near-surface *Fracture systems* is important, in that they present a means of contaminant transfer by groundwater with reduced potential for retardation and also a means of transfer for radionuclides in the gas phase.

The GBIZ characterisation is a key area in which sufficient measurements are required in order to enable its description and analysis for inclusion within the Performance Assessment. The objective of BIOPROTA Theme 2 Task 7 was to support a better account of the treatment of radionuclide migration in the GBIZ by exploring the related accumulation/dispersion/dilution processes that should be considered in order to provide appropriate confidence in Performance Assessment results [BIOPROTA, 2005a]. The following data requirements with relevance to the characterisation of near-surface *Lithostratigraphy* were identified:

- The area over which the groundwater discharge from the near-surface aquifer occurs;
- Sediment erosion, movement and redistribution;
- Seismic and tectonic, and igneous and metamorphic, and related hydrothermal activity.

Table 3.2 provides a summary of information needs in relation to near-surface lithostratigraphy using information presented in Roivainen [2005], SKB [2001], Nirex [2005] and Thorne [2006].

Table 3.2: Information needs in relation to near-surface lithostratigraphy

Type of Measurement	Comment
Geology	
Cover rock types and lithostratigraphy	Required in order to provide basic information to establish the geological structure. Based on aerial photography, mapping surface exposures and bottom sediments and logging samples from augers and boreholes and also petrological examination supported by geophysical investigations.
Elevation of rockhead	Required in order to aid the definition of the hydrogeological model's geometry. Based on a combination of geophysical and intrusive field investigations (e.g. boreholes) depending on the conditions experienced in the study area.
3-D structure of overburden	Required in order to aid the definition of the hydrogeological model's geometry. Based on a combination of geophysical and intrusive field investigations (e.g. boreholes) depending on the conditions experienced in the study area accompanied by the appropriate geophysical and geological interpretations. This should aim to locate structural characteristics (e.g. folds, faults, joints) on both a larger-scale and smaller-scale.
Characteristics of hydrogeologically significant features	To provide a basis for the representation of features within the Performance Assessment calculations. Based on *in situ* borehole testing, interpretation of geological data and mineralogical studies of fracture infill. In the context of the gas pathway, the main interest is in whether continuous fracture flow paths exist from deep subsurface to the soil zone. Therefore, the types of studies that are of interest are those relating to fracture mapping in the subsurface, e.g. through either intrusive or geophysical techniques, or through soil-gas monitoring. In addition, gas migration studies may be undertaken by injecting gas into the subsurface and studying its emergence.
Description of spatial heterogeneity in cover rocks	To provide a basis for the representation of cover rocks within the Performance Assessment calculations. Based on interpretation of geological information gained from desk, field and laboratory studies.
Edaphology	
Identification of soil types and distributions	Forms the basis for subdividing soils. Based on mapping, interpretation of data from aerial photography, imaging data, trial pits, boreholes and geophysical surveys and from soil sampling and laboratory classification tests.
Identification of general soil properties	Includes texture measurements (used to infer hydrological properties), porosity, water content-matrix potential-hydraulic conductivity relationships, flow properties of intact cores using non-sorbed tracers to distinguish macro-pore, fracture and matrix flow components; staining of intact core or use of radio-tracers to visualize flow paths.

3.3.3 Topography

The topography of a site is an important factor in determining the extent of surface water catchments and the potential locations of surface water features and groundwater discharges.

The *Slope* is considered to be of primary important in locating the major features of interest, such as the area over which the groundwater discharge from the near-surface aquifer occurs. *Altitude*, *Erodability* and *Deposition rates* are considered to be of minor importance although consideration of *Erodability* and *Deposition rates* may be required if an evolving biosphere system is being described.

Data collection here should be aimed at the development of a Digital Terrain Model (DTM), a 3-D representation of the topography, which will also be a useful data source for several other aspects of biosphere characterisation (e.g. near-surface lithostratigraphy, water bodies) [e.g. Brydsten and Strömgren, 2005].

3.3.4 Water Bodies

The characterisation of Water Bodies is seen as being of primary importance to Performance Assessment calculations. Contaminant concentrations within water bodies are a key consideration in impact calculations, as they are often a source of water used for drinking and irrigation, and may also be a source of freshwater or marine foodstuffs.

Understanding the *Geometry* of both surface (e.g. lakes) and sub-surface (e.g. shallow groundwater) water bodies is important. A combination of surveying and mapping techniques can be used in order to determine the location of perched and shallow water tables (e.g. measurements of piezometric surface in monitoring boreholes), surface water depth (e.g. depth soundings for lakes and off-shore waters). The locations of rivers, lakes, springs and seepages should be mapped and their geometry and water levels measured along with the delineation of their recharge and discharge areas [SKB, 2001]. In order to correctly determine these parameters, geological and topographical data may also be required to aid the analysis (and interpretation). Temporal and lateral variation may be significant and important depending on local conditions at the study area. As noted previously for long-term Performance Assessments, it is necessary to be able to derive parameters from a time-series database in order that temporal variability can be considered and included where necessary. Determining water body geometries may also aid the initial location of the GBIZ and initially catchment areas may be inferred from a DTM [Thorne, 2006].

Flow rate variation and *Suspended sediment* characteristics have a bearing on the contaminant concentration in a receiving water body and also the transport of contaminants to other water bodies and biosphere media. These can be important factors in determining the degree to which radionuclides entering the biosphere are diluted. Flow rates of surface water bodies are amenable to continuous systems of measurement and monitoring, and suspended sediment determination could be combined with routine sampling campaigns (e.g. to provide samples for chemical analysis, see *Hydrochemistry* below). As well as measurements of currents, an understanding of temperature profiles and salinity distributions within water bodies can be important in determining flow rates.

Oceanographic surveying may be expected to collect data on stratification and salinity as well as measuring components of flow (i.e. direction and magnitude) [e.g. Lindow, 2005; Larsson-McCann *et al*., 2002]. It is also necessary to consider what kind of flow rate measurements are required (e.g. net residual flow) and if data relating to the water surface environment are of interest (e.g. average wave height, storm wave height, wind speed and direction etc.) and the general situation of the water body (e.g. enclosed bay or open water). It is also important to locate and record any freshwater inputs from rivers that may have an influence on the study area.

Although it is possible to measure groundwater flow rates using field techniques, by far the commonest approach is to use computer models to estimate flow rates based on measurements taken in the field and their interpretation. In terms of near-surface hydrological and hydrogeological modelling, the main focus often is to understand the patterns of recharge and discharge on a catchment scale and also to understand the interaction of the localised shallow groundwater with the deeper regional groundwater. This is particularly important in delineating the GBIZ and determining how radionuclides released from the repository may enter the biosphere (e.g. by groundwater discharge to soils, rivers, lakes or coastal waters). GBIZ characteristics of particular note when considering Water Bodies are as follows [BIOPROTA, 2005a]:

- The nature of the hydrogeological flow regime within the near-surface aquifer;
- Groundwater and pore water chemistry;
- Surface water body flow and contaminant transport.

Both natural groundwater discharge and groundwater abstraction from wells and boreholes emphasize the need to understand terrestrial surface and near-surface hydrological systems in both a generic and site-specific context. For assessment purposes, hydrological characterisation has often been at a simplified level, e.g. in terms of partitioning radionuclide discharges from the geosphere between soils and surface water bodies and in defining volumetric water flows into which the radionuclide fluxes are diluted. However, such partitioning and dilution will be arbitrary unless it is underpinned by more detailed hydrological modelling. This implies that protocols should be in place for both hydrological experiments and surface-water catchment characterisation. Table 3.3 provides a summary of the types of studies and associated measurements to support terrestrial hydrological modelling for which protocols are likely to be required.

Table 3.3: Measurements required to underpin terrestrial hydrological modelling

Type of Measurement	Comment
Laboratory studies of samples taken from experimental or repository sites	
Physical properties of soils, subsoils, sediments and parent materials	Includes texture measurements (used to infer hydrological properties), porosity, water content-matrix potential-hydraulic conductivity relationships, flow properties of intact cores using non-sorbed tracers to distinguish macro-pore, fracture and matrix flow components; staining of intact core or use of radio-tracers to visualize flow paths.
Field mapping of experimental plots/catchments or repository areas	
Topographic mapping	For surface water catchments includes overall topographic mapping, identification of interfluves, characterisation of stream channels (width, bank height, long profile, meander pattern). For field plots may only be topographic mapping of a limited part of a hill-slope defined by artificial boundaries.
Soil, subsoil and parent material mapping	Soil types. At the larger scale by series or association. However, at the smaller scale by variations in physical properties, such as texture, to tie into laboratory studies on hydrological properties. Physical properties of subsoils and parent materials will also need to be determined, implying invasive studies from trial pits and boreholes as well as non-invasive and walkover surveys.
Vegetation mapping	Only broad classes of vegetation need to be identified in terms of their capabilities for precipitation interception, retention, control of the pattern of penetration of precipitation to the soil surface, and influence on amounts of evapotranspiration and the depth in soils over which water is abstracted by roots.
Hydrological characterisation and monitoring	At the catchment scale, monitoring will be required of surface water systems (flows, exchange rates, volumes, areas, levels). Meteorological data will be required in standard form. *In situ* measurements of hydrological characteristics in soils will also be required. These include experimental measurements of infiltration as well as monitoring of changes in soil moisture content, matric potential and the height of both regional and perched water tables. Pump tests may be used to study horizontal hydraulic conductivities and flow tests using non-sorbed tracers such as bromide may also be employed. Data on naturally occurring/weapons' test radionuclides such as ^{3}H and ^{14}C may also be useful in characterising the hydrological system. The stable element and isotopic composition of surface waters and groundwaters may also be useful in characterising the mixing of different water bodies in the near-surface environment (see Table 3.2 for chemical parameters).
Experimental flow studies in field conditions	
Definition of the study zone	Identification of an appropriate area and characterisation of its hydrological characteristics, as described above.
Manipulation of the flow domain	Construction of trenches, boreholes or sprinkler systems to add either labelled or unlabelled water to the experimental system.
Monitoring of hydrological characteristics	Installation and operation of field monitoring equipment throughout the experimental period. Such equipment could include access tubes for measuring subsurface water content, tensiometers, water samplers.
Monitoring of tracers for water movement	Includes sampling equipment for tracers such as bromide and electrical conductivity measurements if chloride is used in relatively high concentration as a tracer.

Additional studies are likely to be required to characterise radionuclide migration. These studies can either be of radionuclides or of stable tracers. To a large degree, radionuclide studies are restricted to laboratory environments or to lysimeters maintained in field conditions, as it is important to demonstrate effective containment of the radioactive material. A classification of possible types of experiments is included in Table 3.4.

Table 3.4: Classification of experiments relevant to terrestrial radionuclide migration

Experimental Context	Type of Experiment
Homogenized soil samples	Batch sorption and desorption measurements either at equilibrium or with investigation of kinetics. Can be complemented by mineralogical studies and with studies of sorption/desorption on specific minerals. Normally employs radionuclides as tracers.
Intact or disturbed soil cores or lysimeters	Upward or downward transport of tracers under imposed hydrological regimes. Cores and lysimeters may be either vegetated or unvegetated. Radionuclides are normally used as tracers and their distributions may be determined by either invasive or non-invasive techniques. Cores and lysimeters may be extensively instrumented to determine changing hydrological and geochemical characteristics throughout the experiment. The imposed hydrological regime may either be controlled by the experimenter or may be a monitored natural regime, e.g. for lysimeters maintained in field conditions.
Field plots	Hillslope experiments used to characterise subsurface tracer migration. Conservative tracers may be used to measure water flow (see Table 3.3), but non-conservative tracers may also be used.

In addition, and at the whole catchment scale, contaminant migration can be studied by investigating the spatial distribution of waters with different geochemical signatures. Also, the migration of anthropogenic additions, e.g. nitrate, can be useful. It is possible that information from other types of analogues, e.g. former uranium mine sites may also be useful. However, the issue of the collection and applicability of analogue data is outside the scope of this note and is being addressed in other fora.

Hydrochemistry is also important for several reasons, for example, the selection of parameters such as sorption coefficients and bioaccumulation factors are dependent on an understanding of the chemical constituents and conditions within the water body (e.g. temperature, salinity). Detailed chemical characterisation of water bodies may also be necessary in order to support hydrogeological modelling studies (e.g. in order to determine the origin and residence time of groundwaters). Therefore chemical data is of interest to many parts of biosphere characterisation and may also arise from many areas (e.g. surface waters, soil and sediment pore water, wells, from cored boreholes during drilling, logging and pump tests and long-term monitoring). Examples of chemical determinations included in SKB's characterisation programme are given in Table 3.5, in which different classes of sampling are distinguished in order to meet differing goals [SKB, 2001].

Table 3.5: SKB chemical water sampling and analysis

Class	Description
Sampling for verification of stability	Electrical conductivity, pH, Temperature
Sampling for type classification	Electrical conductivity, pH, Temperature Cl HCO_3 (Optional) $\delta^{2}H$, ^{3}H, $\delta^{18}O$
Determination of main components	Electrical conductivity, pH, Temperature Cl HCO_3 SO_4 Br Cations: Na, K, Ca, Mg, Li, Sr, Si (Optional) $\delta^{2}H$, ^{3}H, $\delta^{18}O$ (Optional) $\delta^{34}S$ (in SO_4), $\delta^{37}Cl$, $\delta^{87}Sr$, $\delta^{10}B$ (Optional) ^{14}C, $\delta^{13}C$
Complete chemical characterisation	Electrical conductivity, pH, Temperature Cl HCO_3 SO_4 Br DOC Cations: Na, K, Ca, Mg, Fe, Mn, Li, Sr, Si SO_4 as S $\delta^{2}H$, ^{3}H, $\delta^{18}O$ HS^{-}, NH_4 (Optional) NO_2, NO_3, PO_4, F^{-}, I^{-}
Complete chemical characterisation with special analyses	Electrical conductivity, pH, Temperature Cl HCO_3 SO_4 Br Temperature DOC Cations: Na, K, Ca, Mg, Fe, Mn, Li, Sr, Si SO_4 as S ^{2}H, ^{3}H, ^{18}O F^{-}, I^{-} HS^{-}, NH_4, NO_2, NO_3, PO_4 (Optional) $\delta^{34}S$ (in SO_4), $\delta^{37}Cl$, $\delta^{87}Sr$, $\delta^{10}B$ (Optional) ^{14}C, $\delta^{13}C$ (Optional) ^{226}Ra, ^{228}Ra, ^{222}Rn (Optional) U and Th isotopes (Optional) U, Th, lanthanides, heavy metals (Optional) Dissolved gas (including $\delta^{18}O$, $\delta^{13}C$, $^{3}He/^{4}He$), bacteria (Optional) colloids (Optional) Humic and fulvic acids (Optional) on-line pH, Eh

3.3.5 Biota (Fauna and Flora)

Although a detailed investigation of the biota will be a necessary part of any EIA to support a licence to construct a repository, it is not necessarily required for the purposes of long-term Performance Assessment.

The requirements relating to the characterisation of biota for a long-term Performance Assessment will be strongly influenced by the assessment context and specifically the approach to the calculation of potential impacts from the repository which is expected to vary between countries. National guidance and regulations may require the repository developer to undertake different calculations to estimate impacts for a variety of endpoints. In turn, these requirements will have a strong influence on this aspect of the biosphere characterisation. For example, the assessment context may require that the only endpoint considered is the estimation of annual effective dose to individuals based on present-day habits and behaviour. This may require relatively simple characterisation of the biota, e.g. investigating land uses in relation to the biota (covering methods of agriculture and forestry practices). Alternatively, should the assessment context require the estimation of environmental impacts as one of the calculation endpoints, then this may be expected to require a much more detailed consideration of the nature, extent and diversity of the biota. Table 3.6 summarises the techniques suggested by SKB for biota characterisation [SKB, 2001].

Table 3.6: Methods for characterisation

Method	Parameter
Land	
Inventory of key habits	Key habitats and general biotope protection
Vegetation and biotope mapping • Existing material • Aerial photos • Map interpretation • Field studies	Vegetation and biotope map Forestry • quantity • production • rotation • age structure Agriculture • production of crops Vegetation type • population/production • species of vascular plants, fungi, lichens, mosses and algae
Compilation of red-listed species	Red-listed species
Biomass and production • Existing material • Area assessment	Hunting, allotment, felling statistics • Species, number and occurrence • Biomass • Production
Aquatic	
Bottom mapping • Vegetation and animal zonations • Bottom type distribution	Vegetation zonation map
Sampling • Water fetching • Dip-netting • Bottom samples • Production measurement	Species compositions and quantity of fauna and flora Production
Fishing • Existing material • Net fishing • Electrofishing • Echo sounder	Species composition Toxic pollutants/radionuclides in fish Fishing licences Catches Professional fishermen

When calculating potential impacts either to man or non-human biota the most common approach within Performance Assessments is to assume a linear dependence on concentration and equilibrium approach to the estimation of radionuclide concentration within environmental media. Such an approach uses generic parameters and relationships to represent processes such as root uptake in plants and transfer across the gut wall in animals [e.g. IAEA, 1994]. However, rather than using generic data, site-specific values may be derived, and laboratory and field studies could be used to characterise the uptake of radionuclides by plants and animals. In this context, it is useful to recognize distinctions between:

- Experiments at the pot, column, lysimeter and field plot scales on foliar uptake of radionuclides by plants relevant to spray irrigation;
- Experiments at the pot, column, lysimeter and field plot scales on radionuclide uptake by plants from soil relevant either to soil contaminated by irrigation or by upwelling groundwater;
- Experiments on radionuclide transfers to animals maintained in laboratory conditions;
- Measurements on stable element compositions of soils, plants and animals in field conditions from which transfer factors can be inferred.

In the context of foliar uptake, radionuclides can be administered to foliage through local, topical application or through simulated irrigation. Such experiments can be used to study both retention of the applied material and translocation within the plant.

In the context of root uptake, there is a place for studies on uptake from solution culture, as well as from whole soils. Solution culture experiments are highly artificial, but are a convenient tool for investigating factors such as the effects of different chloride and nitrate concentrations in solution on the uptake of ^{36}Cl. At the pot scale, the initial distribution of the radionuclide in the soil system may be defined, but there is only limited scope for imposing various hydrological regimes and investigating their effects on plant uptake. At the column and lysimeter scales, plants can be incorporated in the types of experiments identified in Table 3.3. At the field plot scale, the emphasis is likely to be on experiments with stable tracers, except in specific circumstances such as experiments conducted on existing licensed nuclear sites. Stable tracers include studies with isotopically modified elements, e.g. water enriched with deuterium and, in particular, carbon with a distinct ^{13}C signature. Use of ^{13}C as a tracer is relevant to the migration and plant uptake of ^{14}C arriving in the soil zone by either gas or groundwater transport.

It is thought unlikely that many animal studies will have been conducted specifically in the context of solid radioactive waste disposal. It is, therefore, proposed to identify the few specific examples that exist and to classify them further at a later stage. In broad terms they are likely to relate mainly to gastrointestinal absorption, retention in tissues and transfers to milk and eggs. They may be kinetic studies or relate to the determination of 'equilibrium' transfer factors and may be conducted in laboratory or field conditions. It should also be noted that animal experiments and elated environmental monitoring carried out for present day discharges and releases to the environment is also be relevant to solid waste disposal. Therefore, the entire body of literature on animal kinetic data is potentially relevant.

An alternative to the development of site specific parameters for equilibrium food chain models could be an approach to develop a specific activity model. For example, see the introductory case study of ^{36}Cl given in Section 1.

3.3.6 Human Activities

The description of human communities and activities may be a necessary component of biosphere characterisation 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[1]. 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 which may be a requirement of the assessment context.

As noted previously the definition, identification and description of exposure groups for Performance Assessment calculations is not within the scope of BIOPROTA. This is due to variations in regulatory requirements between the members' countries. In terms of characterisation requirements, it is a relatively straightforward task to identify human habits and diets by means of local surveys. The influence of the characteristic *Human behaviour in relation to biosphere system* includes some aspects that are addressed in Theme 2 Task 1: Model Review and Comparison for Spray Irrigation Pathway [BIOPROTA, 2005b] and Theme 2 Task 4: Model Intercomparison with Focus on Accumulation in Soil [BIOPROTA, 2005c] and the characteristic *Human behaviour in relation to exposure* is considered relevant to Theme 2 Task 2: Modelling the Inhalation Exposure Pathway [BIOPROTA, 2005d].

3.3.7 Summary

Table 3.7 summarises the biosphere characterisation requirements based on the subdivision of the biosphere using the Type I components outlined in BIOMASS and Table 3.8 summarises the categories of protocols that could be used as part of a biosphere characterisation programme in order to address the information needs.

[1] 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 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 3.7: Summary of biosphere components for characterisation

Component	Importance to Performance Assessment calculations
Climate and Atmosphere	Precipitation and temperature measurements are of primary importance and are required in order to calculate the water balance of the biosphere on a large scale but also at a detailed scale to determine the soil water balance. Temperature and Solar radiation may also have a bearing on agricultural practices and human activities. Given the long-term nature of Performance Assessment calculations it is generally considered desirable to analyse long-term time series data. Temporal variability has general relevance to the adequate characterisation of various natural events which may occur on a series of different timescales. Spatial variability may have relevance where the existence of microclimates is a possibility.
Near-surface lithostratigraphy	The characterisation of soil types, texture and compositions are important factors in contributing to the development of hydrogeological models and also in the consideration of future land-uses. Characterisation of the near-surface geology is key to developing models to estimate potential impact in Performance Assessment calculations. In particular, characterisation of the geometry, structure, composition and hydrogeologically significant structures and their properties is crucial to being able to determine model boundaries, processes and parameters. Characterisation of the GBIZ is another area of crucial importance to enable its treatment appropriately within Performance Assessment calculations.
Topography	Topography is considered to be of primary importance in determining the extent of surface water catchments and the potential locations of surface water features and groundwater discharges. The development of a DTM is advantageous in capturing the required topographic influences and is also a useful data source for other aspects of biosphere characterisation (e.g. geology, hydrology).
Water bodies	Contaminant concentrations within water bodies are key inputs to impact calculations as such water bodies are often a source of water used for drinking and irrigation, and may also be a source of freshwater or marine foodstuffs. The location of water bodies may have topographic controls and may also be related to the location of the GBIZ. Chemical characterisation of the water bodies is important in supporting the development of hydrological and hydrogeological models, determining radionuclide transport and bioaccumulation parameters and other indicators.
Biota (Flora and Fauna)	Requirements for characterisation here may vary depending on the endpoints stated within the assessment context. However, a secondary requirement may exist in the need to derive site-specific data to describe the accumulation of radionuclides within flora and fauna rather than relying on equilibrium approaches based on generic data.
Human community	Not considered within BIOPROTA however, some characteristics of human behaviour are relevant to work carried out under Theme 2 (Tasks 1, 2 and 4).

Table 3.8: Categorisation of Experimental and Monitoring Protocols

Category	Comments
Properties of Soils, Subsoils, Sediments and Parent Materials	
Texture	Typically percentages of sand, silt, clay and organic matter content. May include more detailed particle size analyses.
Porosity	Both total porosity and estimates of matrix, macropore and fracture porosity. Includes evaluations of pore geometry, e.g. connectivity and tortuosity.
Mineralogy	Both descriptive and in terms of sorption potential, e.g. Cation Exchange Capacity or through direct measurements of sorption. See also sorption to soils.
Hydraulic Properties	Water content – matric potential – hydraulic conductivity relationships. Emphasis should be on measurements on intact material either *ex situ* (e.g. soil cores) or *in situ* (e.g. falling head measurements or pump tests).
Flow Paths	Staining techniques and tracer studies.
Field Mapping	Classification system used. Scales and techniques of mapping. Characterisation of small-scale variability. Interpretation through statistical techniques, e.g. use of semi-variograms.
Invasive Field Studies	Techniques of borehole and trial pit construction and logging. Hydraulic testing undertaken *in situ* in boreholes and trial pits.
Field Mapping	
Topography	Surface water catchment, hillslope and field plot scales. Characterisation of stream channels.
Vegetation	Classification system used. Scales and techniques of mapping. Characterisation of small-scale variability. Interpretation through statistical techniques, e.g. use of semi-variograms.
Hydrology	Surface water systems. Spatial and temporal variations in soil water content, matric potential and phreatic surface heights.
Geochemistry	Geochemical characteristics of water bodies and suspended material that they contain. Geochemical signatures of different water bodies, including isotopic ratios and naturally occurring/weapons' test radionuclides.
Field Measurements of Water Flow	
Basis of Experiments	Selection of experimental areas. Overall techniques for delimiting flow domain and imposing altered boundary conditions.
Flow Monitoring	Includes borehole monitoring of water levels, use of tracer techniques and use of non-invasive geochemical techniques, such as resistivity measurements to track a stable chloride plume. Use of automated devices to measure temperature, salinity and flow components of surface water bodies.
Field Measurements of Gas Flow	
Basis of Experiments	Selection of experimental areas. Overall techniques for delimiting flow domain and imposing altered boundary conditions.
Flow Monitoring	Monitoring of injected bulk gas transport, use of tracer techniques and studies of naturally occurring soil gases, including radon.
Sorption to Soils, Subsoils, Sediments and Parent Materials	
Homogenized samples	Batch sorption techniques including complementary studies on the physical and chemical characteristics of the sample and solution.
Cores and Lysimeters	Construction and packing. Vegetation techniques. Imposed hydrological conditions. Hydrological monitoring, e.g. techniques for determining moisture content and matric potential. Non-destructive and destructive monitoring (solution composition, redox characteristics, tracer distribution *etc.*). Temperature monitoring (for correction of hydrological measurements and in studies of frozen ground effects). Note that this relates closely to hydraulic property studies.
Field Plots	Tracers used and analytical techniques employed. Characterisation of field plots discussed above under field measurements of water flow.
Uptake by Plants	
Foliar Application	Technique of administration. Radionuclides used. Sampling regime and analytical techniques.
Solution Culture Experiments	Reasons for studies. Plant types. Culture conditions. Radionuclides used and analytical techniques.
Pot, Column and Lysimeter Experiments	Basis of experiments. Overall design. Hydrological characterisation. Plant types. Monitoring of plant growth (e.g. standing biomass, leaf area index, root distribution). Radionuclides used and analytical techniques.
Field Plots	Selection of experimental areas. Addition of tracers. Sampling and analysis techniques.
Uptake by Animals	
-	Thought to be a limited topic on which few studies will have been conducted.

4 CONCLUSIONS

A review of the basis for biosphere characterisation has been undertaken noting the progression from reliance on generic or regional data to the need to derive and use site-specific data as repository development progresses.

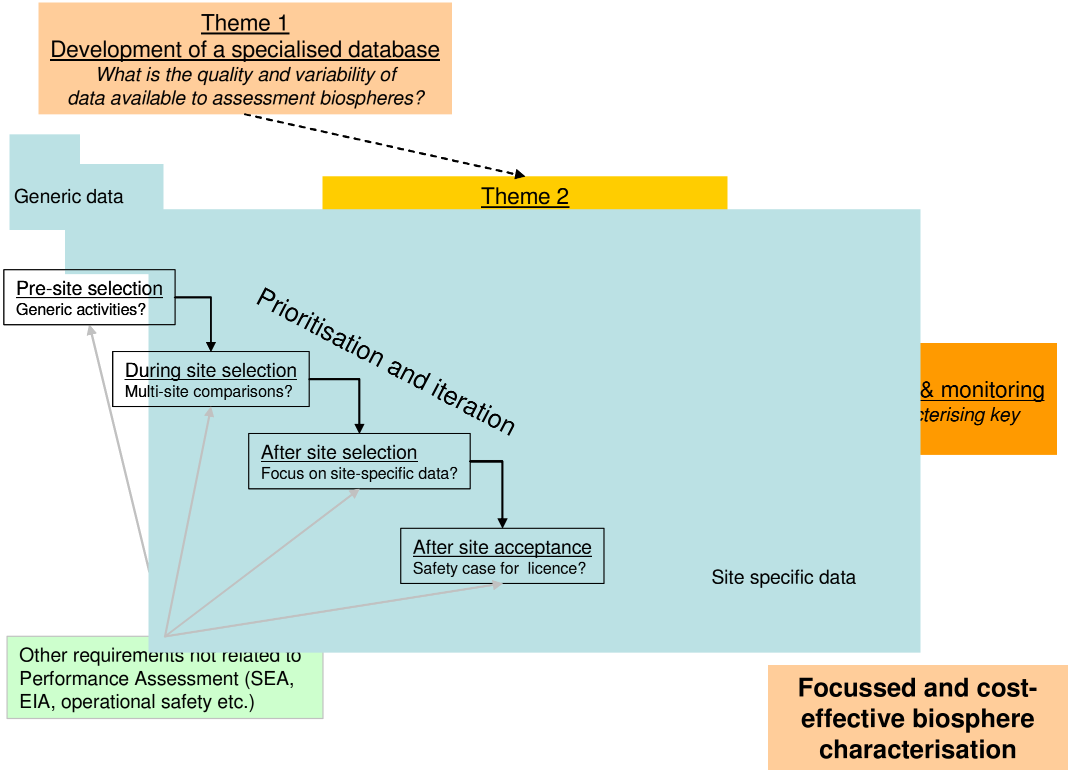
The Type I components developed by BIOMASS to aid biosphere description and analysis have been used as a means of discussing the various data requirements and measurement protocols. It is recognised that, in some circumstances, it may be useful to initially provide a historical description of characteristics in order to put their present-day description into context. Also noted was the iteration between periods of active characterisation and interpretation, although such aspects were not considered in the generic discussion in order to simplify the presentation.

The report focuses solely on the requirements of a long-term Performance Assessment and does not give detailed consideration to the biosphere characterisation requirements of an EIA, operational safety assessment or other supporting studies (e.g. design solution for repository surface support facilities).

Three fundamental questions were asked at the outset, one from each BIOPROTA theme.

Theme 1 *What is the quality and variability of data available to assessment biospheres?*
Theme 2 *Which biosphere parameters is the estimation of impact sensitive to?*
Theme 3 *What are the best methods for characterising key biosphere parameters?*

Answering these questions using output from BIOPROTA and knowledge of the requirements of biosphere characterisation activities to support repository development should, therefore, enable the planning of a focussed and cost-effective biosphere characterisation programme with a clear and logical audit trail, as shown in the flowchart below.


Theme 1
Development of a specialised database
What is the quality and variability of data available to assessment biospheres?
Generic data
Theme 2
Pre-site selection
Generic activities?
During site selection
Multi-site comparisons?
After site selection
Focus on site-specific data?
After site acceptance
Safety case for licence?
Prioritisation and iteration
& monitoring
terising key
Site specific data
Other requirements not related to Performance Assessment (SEA, EIA, operational safety etc.)
Focussed and cost-effective biosphere characterisation

5 REFERENCES

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